Prins Maurits Laboratorium TNO

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Wolf II: Measurement results of the 2 kg TNT experiment in the crew aft sleeping compartment

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Summary

Within the framework of the research into the vulnerability of ships, an experimental investigation took place in 1989 aboard the frigate "WOLF" of the "Roofdierklasse" (PCE 1604 class) (Wolf, Phase II).

In this report the recordings of an instrumented experiment in the crew aft sleeping compartment are presented. During this experiment, a non-fragmenting charge of 2 kg TNT was initiated.

Samenvatting

In het kader van het onderzoek naar de kwetsbaarheid van schepen zijn in 1989 een aantal experimenten uitgevoerd op het fregat "WOLF" van de Roofdierklasse (PCE1604 class) (Wolf, Fase II).

In dit rapport worden de meetresulaten gepresenteerd van een geïnstrumenteerde beproeving van het manschappen slaapcompartiment op het achterschip. Tijdens dit experiment werd een kale, 2 kg TNT lading tot ontploffing gebracht.

CONTENTS

1 INTRODUCTION

In order to obtain quantitative as well as qualitative information on the effects of internal and external explosions on a frigate, a number of (instrumented) experiments were performed on the frigates "FRET" and "WOLF" (Figure 1). These are Roofdier class frigates, formerly United States Navy PCE1604 class, which were decommissioned by the Royal Netherlands Navy. A general overview of the Roofdier trials is given in Table 1.

Table 1 A general overview of the Roofdier trials

Fret I	June/September 1987	(v.d. Kasteele and Verhagen, 1989)
Wolf I	October/ November 1988	(v.d. Kasteele and Zwaneveld, 1989)
Wolf II	September/October 1989	(Verhagen and v.d. Kasteele, 1992)

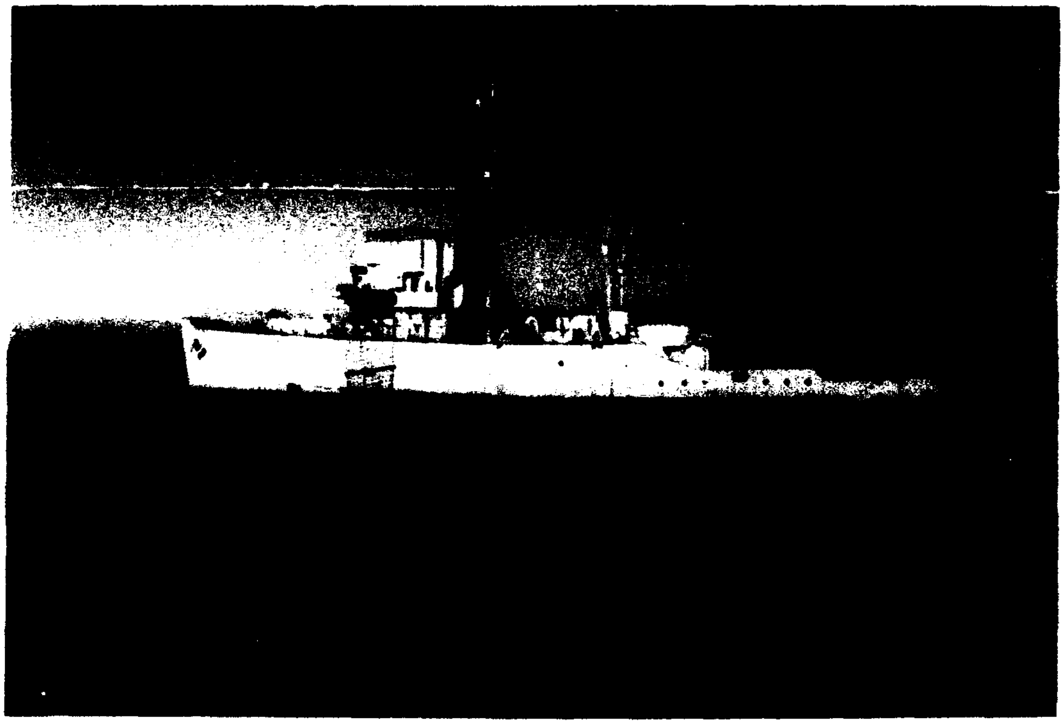


Figure 1 Wolf frigate

Pressure, strain, acceleration etc. were recorded during the Wolf Phase II bare charge experiments. These experiments were performed in the crew aft as well as the crew forward sleeping compartment. In the crew aft sleeping compartment, the 2, 5.5 and 15 kg TNT bare charge experiments were performed on one day. The volume of this compartment was ±77 m^3, thus realizing a "charge density" of ±0.026, ±0.072 and ±0.20 kg/m^3.
The 3 and 12 kg TNT bare charge experiments were also performed in the crew forward sleeping compartment on one day. The volume of this compartment was ±105 m^3, thus resulting in a "charge density" of ±0.029 and ±0.11 kg/m^3.
During these Phase II experiments special attention was paid to the blast resistance of the watertight doors (i.e. the 2, 3 and 5.5 kg TNT experiments), the resistance of the structure (the 12 kg TNT experiment) and the rupture of structural elements (the 15 kg TNT experiment).

The recordings of the instrumented Wolf Phase II experiments presented conform to the previous reports dealing with the recordings of the Fret and Wolf Phase I experiments. Each report can be regarded as an independent report. It goes without saying that it is not within the scope of these reports to discuss the recordings in detail or even to compare the recordings with theoretical predictions. That will be an integral part of the reports presented by van Erkel (1992).
Nevertheless, some additional information is given concerning the reliability of the presented recordings.

Due to the increased knowledge and experience gained from the Fret and Wolf Phase I trials, modified mounting and protection techniques were used during the Wolf Phase II trial. It is for this reason that a separate report deals with the general background information as well as the mounting and protection methods used. For the sake of completeness, a description is also given of the registration equipment and the signal analysis system used.

This report deals with the bare 2 kg TNT experiment in the crew aft sleeping compartment.

Some general remarks on the experiment are given in Chapter 2, as well as some specific information on the charge used. In the following chapters, the recordings are presented.
Offset elimination was carried out. The time axis used was related to the moment of ignition of the charge (t=0).

Because the 2, 5.5 and 15 kg TNT experiments in the sleeping compartment were performed in one day, there was not much time between the experiments for the technicians to adjust the settings of the registration equipment. Instead, a general setting was used for these experiments based on the maximum charge (15 kg TNT) to be used on that particular day. This will have a negative effect upon the signal-to-noise ratio, however. Only a few signals could be adjusted between the experiments.

Some abbreviations often used are BHD (Bulkhead), SB (Starboard), PS (Portside) and CL (Centre line frigate).

2 DESCRIPTION OF THE EXPERIMENT

2.1 The objective of the experiments

One of the objectives of the ROOFDIER trials is the validation of the "DAMINEX" code as developed by the Weapon Effectiveness Department of TNO - Prins Maurits Laboratory.
The DAMINEX code determines the structural damage to a frigate due to internal blast. A number of theoretical assumptions were made during the development of this code, which however may have a large influence on the final simulation results.
In general, the damage caused by the experiments is registered visually. It is for this reason that a lack of quantitative information is still apparent. The specific goal of the Roofdier experiments is to gain more quantitative as well as qualitative information by performing well-documented experiments. This information will be used to validate (or even modify) the DAMINEX code.

2.2 Experimental set-up

Two crew sleeping compartments were chosen by the Weapon Effectiveness Department for the instrumented experiments: the crew forward sleeping compartment and the crew aft sleeping compartment. These two compartments correspond with the sleeping compartments used during the FRET experiments. As a consequence, these experiments can be compared with the FRET experiments, although during the latter, (bare) charges of 8 kg and 12 kg TNT were used.

The crew aft sleeping compartment (height: 2.2 m, length: 4.3 m, width: 7.2 m - 9.4 m) was cleared as much as possible of all obstacles. The 2 kg TNT experiment was the first experiment carried out in this compartment. To simulate one aspect of the hull's penetration by the warhead, and to allow venting of the pressure, a hole (diameter = 40 cm) was made in the centre of the SB hull of the compartment in which the experiment took place. During this particular experiment, half of the venting hole was closed with a steel plate.

The charge used during this experiment consisted of four rectangular blocks of TNT (500 grams, size: 45.6 x 70.8 x 105.0 mm^3) resulting in a rectangular bare charge of 2 kg TNT with dimensions 91.2 x 141.6 x 105 mm^3, (see Figure 2). The charge was located in the centre of the compartment at midheight. The charge orientation was vertical, thus effecting a symmetry with respect to the centre line of the ship and the line perpendicular to the centre line. The charge was ignited with one electrical detonator (No. 8) and a booster of three RDX cartridges (L/D=1, D=50 mm) located at the centre in the bottom of one of the four blocks, as indicated in Figure 2. An impression of the experimental set-up before the 2 kg TNT experiment was performed is given in Figure 3.

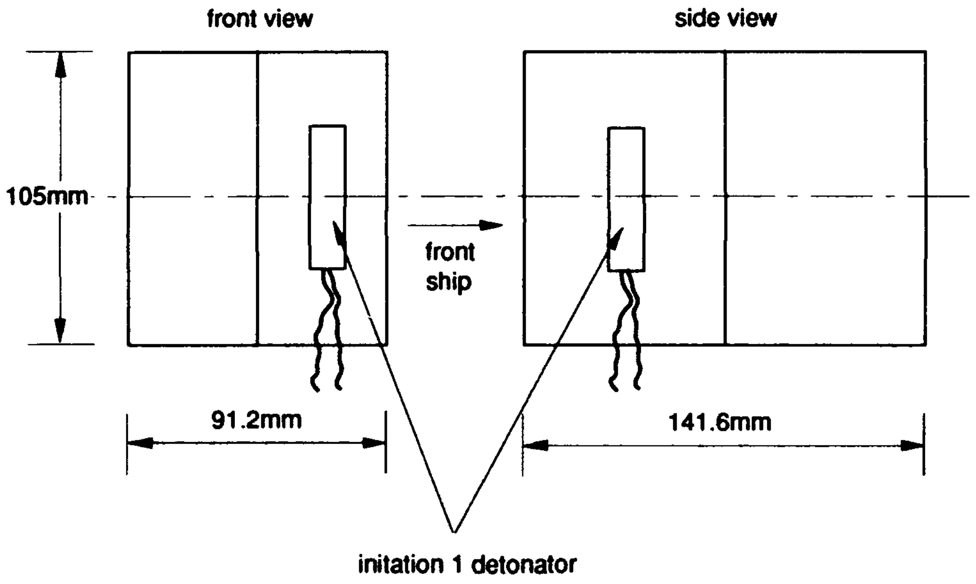


Figure 2 Geometry of the charge

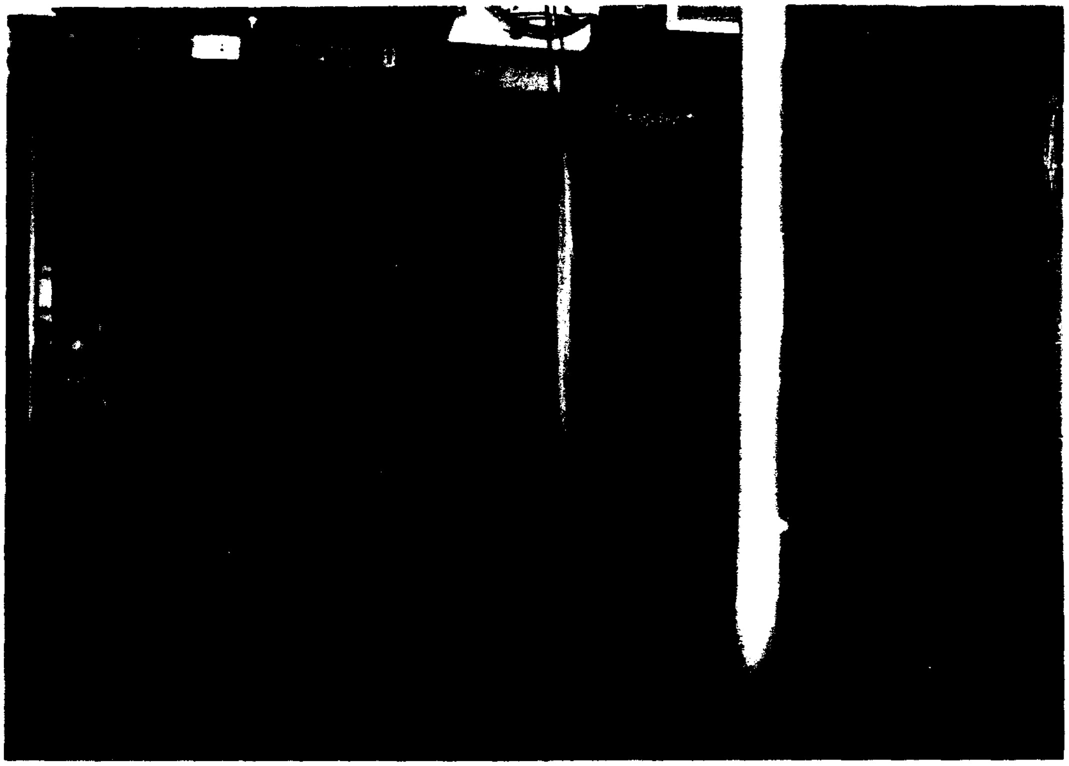


Figure 3 Impression of the experimental set-up

3 PRESSURE MEASUREMENT

3.1 Position of the pressure transducers

To measure the overpressure, eight piezo-electric pressure transducers B1-B8 were used, all mounted in the experiment compartment. B1 and B2 were mounted on the hull of the frigate whereas B3-B8 were flush mounted on the bulkheads. It must be noted that transducer B1 was located in the hull in the vicinity of the 40 cm diameter venting hole. All transducers were mounted at about midheight in the compartment. The positions of the transducers are summarized in Table 2 and shown schematically in Figure 4.

Table 2 Position of pressure transducers

Device	Height	Mounting position	
B1 (1)	115 cm	on hull SB,	155 cm from BHD 78
B2	115 cm	on hull PS,	155 cm from BHD 78
B3	114 cm	on BHD 78,	35 cm from CL
B4	114 cm	on BHD 78,	176 cm from CL
B5	114 cm	on BHD 78,	328 cm from CL
B6	115 cm	on BHD 71,	368 cm from CL
B7	114 cm	on BHD 71,	259 cm from CL
B8	114 cm	on BHD 71,	102 cm from CL

(1) in vicinity of venting hole

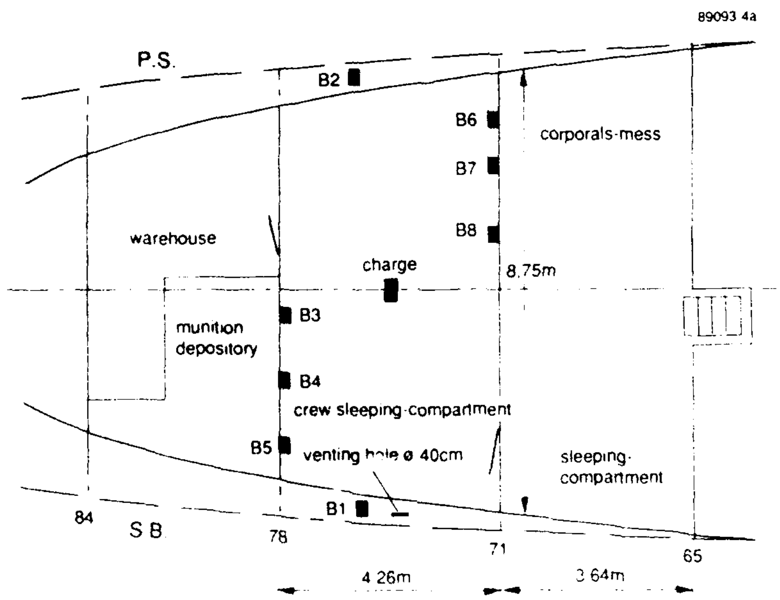


Figure 4 Schematic illustration of the positions of the pressure transducers

3.2 Discussion of the pressure measurements

The recorded pressures are presented in Figures 5, 6 and 7. The first impression of the individual signals is very encouraging. The signals show very "classical" behaviour.

In order to get an impression of the accuracy of the measurements, the first peak pressure and the arrival time of each signal were determined and gathered in Table 3.

Due to the charge geometry, it was not possible to compare these recordings directly with theoretical predictions. Notwithstanding, all the charge used was modelled as a spherical charge which is ignited in the centre. With these simplifications, the theoretical predictions of the maximum (face-on) peak pressure and arrival time of the shock front could be derived with Baker (1983, Figures 2.45 and 2.46). These theoretical predictions are also included in this table.

Table 3 Comparison of experimental and theoretical (first) peak pressure and arrival time

Device	d(D,C)	Z	Peak pressure		Arrival time	
			Exp.	Theor.	Exp.	Theor.
	[m]	[m/kg$^{1/3}$]	[kPa]	[kPa]	[ms]	[ms]
B1	4.25	3.37	340	150	6.5	5.6
B2	4.25	3.37	185	150	6.7	5.6
B3	2.15	1.70	1580	1150	1.5	1.7
B4	2.75	2.18	1360	550	2.5	2.8
B5	3.95	3.14	190	180	4.8	5.0
B6	4.25	3.37	210	150	5.9	5.6
B7	3.35	2.66	560	300	4.0	3.8
B8	2.35	1.87	3375	950	2.0	2.1

d(D,C) : distance between Device and Charge

Z : scaled distance [m/kg$^{1/3}$]

Theoretical values based on a spherical charge which is ignited in the centre (Baker 1983, Figures 2.45 and 2.46).

From this table it appears that, in general, the experimental arrival time corresponds very well with the theoretical prediction, although the experimental arrival time of B1 and B2 is 1 ms later than the theoretical prediction. Regarding the peak pressures, it appears that the experimental and theoretical values agree well for some transducers. However, it must be noted that for some devices, the theoretical prediction underrates the recorded pressure by up to a factor 3.

The arrival time of the shock front will not be influenced by the angle of incident of the shock front and the wall. The (peak) face-on pressure however depends on the angle of incidence. The theoretical predictions of the peak face-on pressures were based on a perpendicular incidence angle, which corresponds with the experimental set-up only for transducers B1, B2, B3 and B4, but differs (slightly) for the remaining devices.

It must also be noted that the blast devices were located almost symmetrically with respect to the charge: devices B1 and B2, devices B3 and B8, devices B4 and B7, and devices B5 and B6. Due to reflections, the influence of the (local) geometry will become more pronounced at a later stage.

Consider the first part of the recordings of these device combinations in more detail:

1 Devices B1 and B2: These signals show a good correspondence up to 10 ms. From that particular moment, the B1 transducer behaves strangely which may be due to the venting hole. Transducer B2 however still behaves normally.
2 Devices B3 and B8: The correspondence of the signal shapes is remarkable, although a difference in arrival time of 0.5 ms can be seen. B8 shows a second peak which may be due to reflections of the local geometry.
3 Devices B4 and B7: These two devices show no correspondence: the peak value and the arrival times differ considerably.
4 Devices B5 and B6: The shape and peak pressures show a close resemblance although the arrival times differ by 1 ms.

It is evident that the pressure devices were (almost) symmetrically mounted with respect to the centre of the charge. The simplifications made for the theoretical predictions did not hold. The discrepancy in the response of the symmetrically mounted devices can thus only be made plausible by taking into account the geometry of the charge, the place the charge was ignited, the venting hole near device B1 and the local geometry. Some blast signals show a drift which may be due to temperature influences. However, the pressure signals as presented in this chapter seem to be reliable.

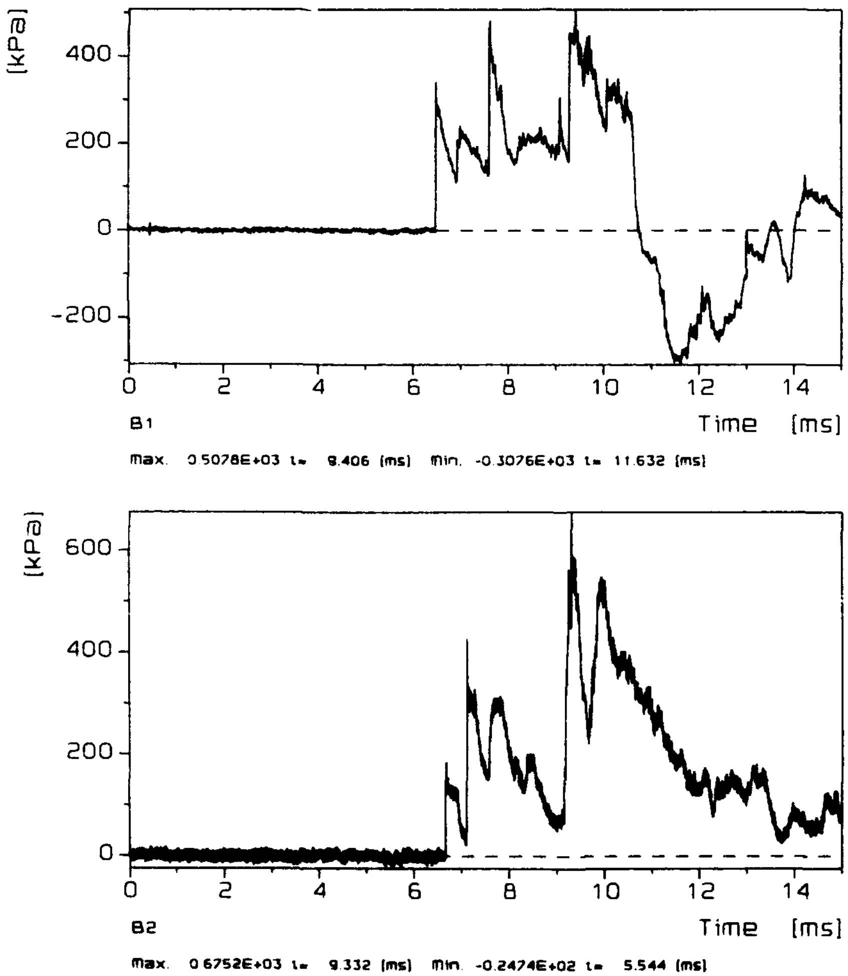


Figure 5 **Pressure signals B1 (SB hull) and B2 (PS hull)**

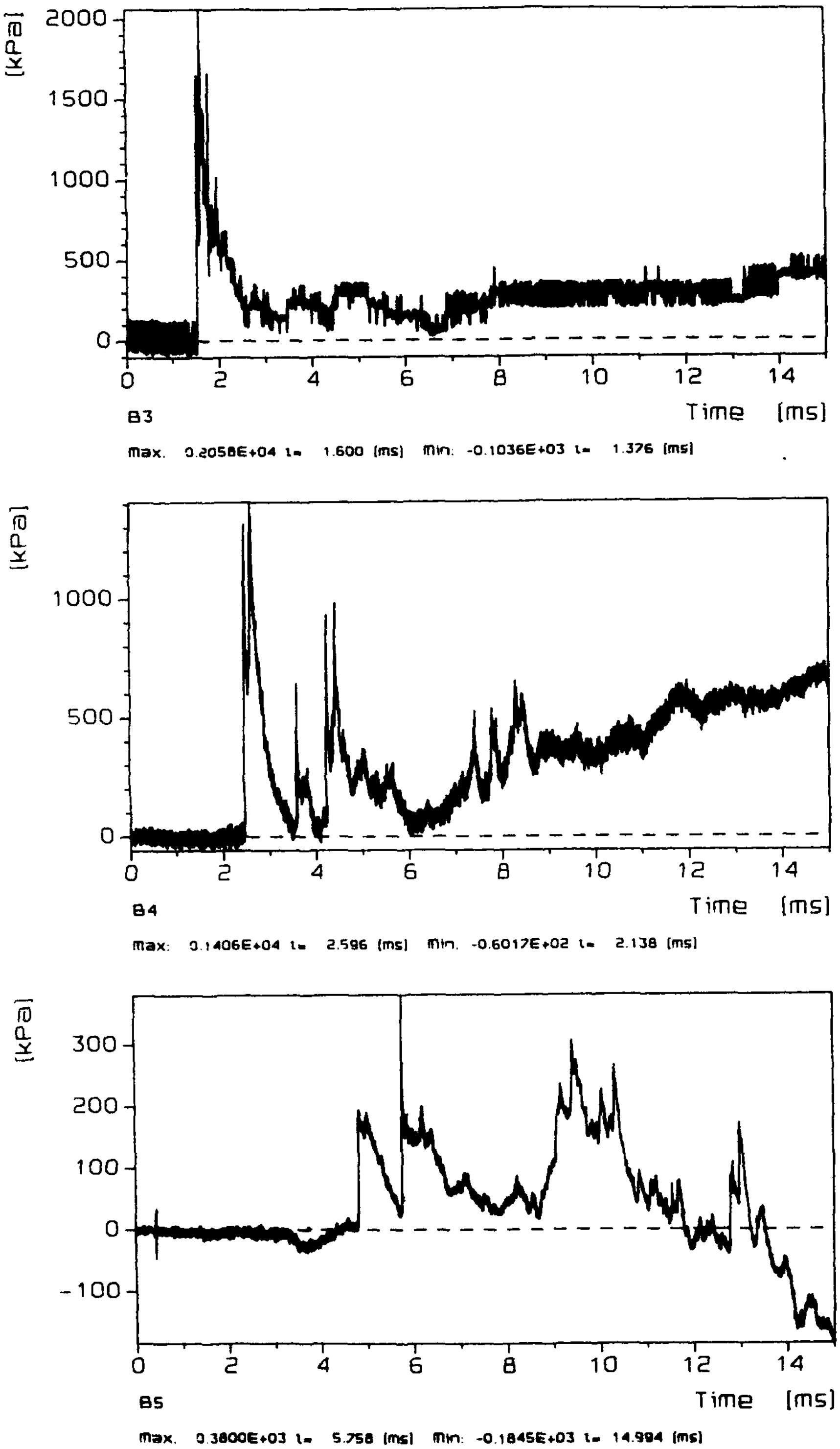


Figure 6 Pressure signals B3, B4 and B5 (BHD 78)

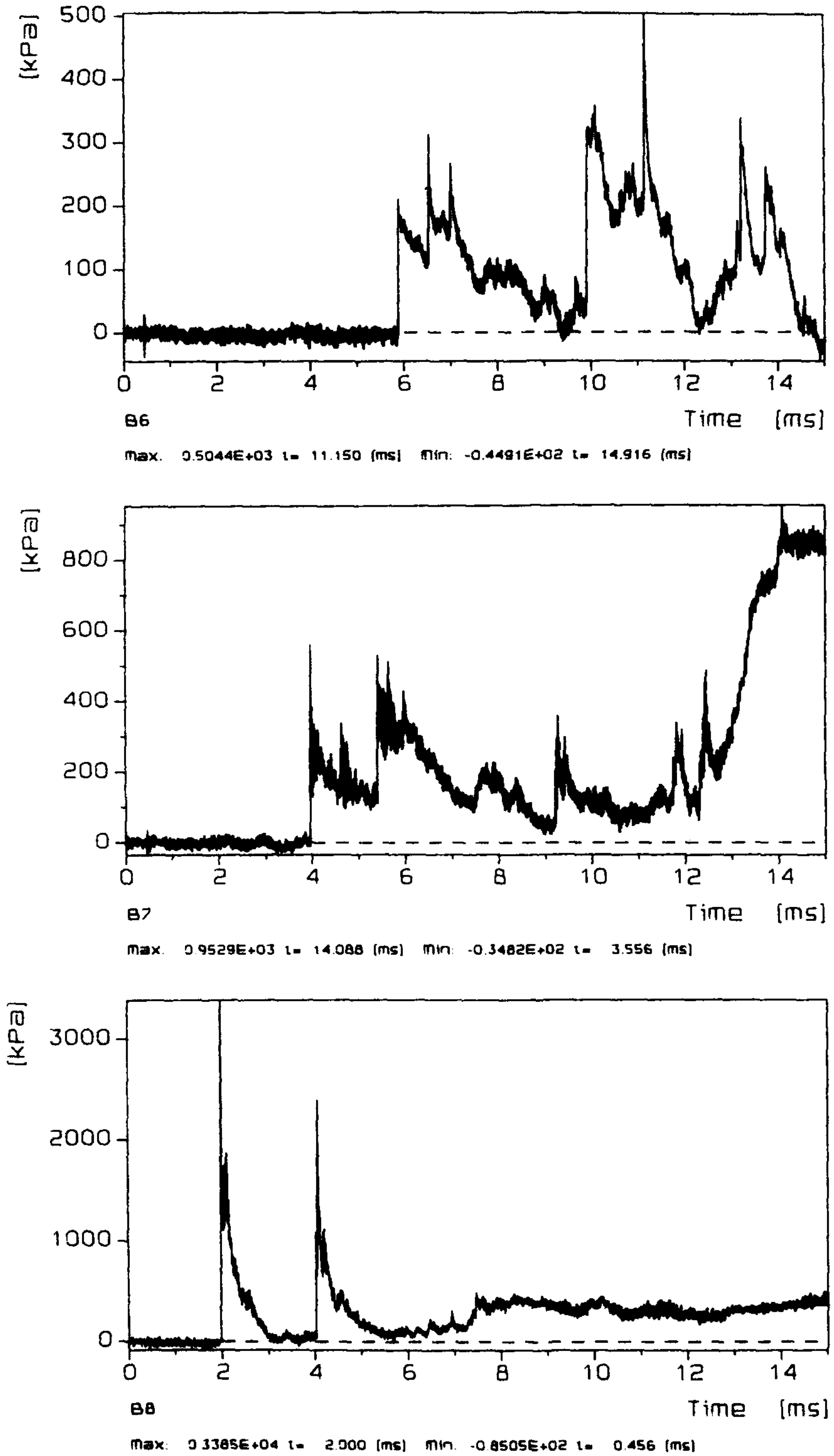


Figure 7 Pressure signals B6, B7 and B8 (BHD 71)

4 QUASI-STATIC PRESSURE MEASUREMENT

4.1 Position of the quasi-static pressure transducers

The quasi-static pressures were registered with piezo resistive transducers at seven different locations (Q1-Q7). Two transducers (Q1, Q2) were placed in the crew sleeping compartment (where the experiment took place). The remaining five transducers were placed in the neighbouring compartments, i.e. three transducers (Q3, Q4, Q5) in the corporals' sleeping quarters/mess, one (Q6) in the munition depository and one (Q7) in the warehouse. The positions of the transducers are summarized in Table 4 and shown schematically in Figure 8.

Table 4 Position of the quasi-static pressure transducers

Device	Height	Position
Q1(1)	125 cm	15 cm in front of the SB hull, experiment compartment
Q2	127 cm	17 cm in front of the PS hull, experiment compartment
Q3	118 cm	246 cm from SB, on BHD 65, corporals' sleeping quarters/mess
Q4	113 cm	305 cm from PS, on BHD 65, corporals' sleeping quarters/mess
Q5(2)	115 cm	200 cm behind door BHD 71, hull SB, corporals' sleeping quarters/mess
Q6	113 cm	141 cm from BHD 78, munition depository
Q7	113 cm	160 cm from BHD 78, warehouse

(1) in vicinity of the venting hole

(2) membrane direction BHD 65 (face off)

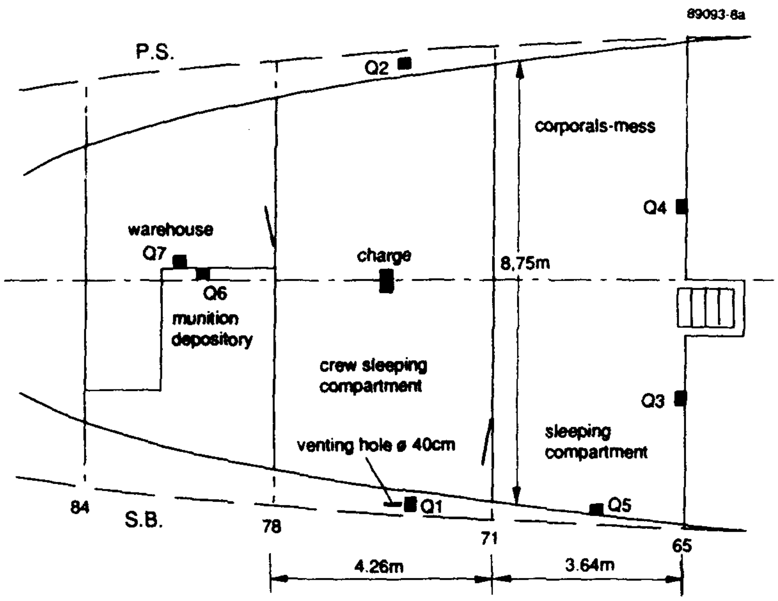


Figure 8 Schematic illustration of the position of the quasi-static pressure transducers

4.2 Discussion of the quasi-static pressure measurements

The recorded quasi-static pressures are presented in Figures 9, 10, 11 and 12. Keeping in mind that there are no obstacles in the experiment compartment, the main difference in the Q1 and Q2 signals, the decay of the pressure, may be attributed to the venting hole near device Q1.

Devices Q3, Q4 and Q5 were mounted in the corporals' mess and sleeping quarters, which were one compartment. Walls etc. were removed before the experiments took place. This compartment is connected to the experiment compartment only by the door in BHD 71.

The pressure in the compartment may occur due to leakage from the door during the experiment. Note that the membrane of Q5 is in the direction of BHD 65. It appears that Q4 and Q5 show a close resemblance, while Q3 differs considerably. This may be attributed to the location of device Q3: behind the door in BHD 71.

The munition depository (Q6) has no direct connection with the experiment compartment; this compartment can only be reached from the upper deck. The pressure in this compartment is due to a rupture in the bulkhead near the floor. It appears that Q6 reacts quicker than Q1 and Q2. This may be an indication that the crack in the wall occurs immediately when the shock front reaches the wall.

The warehouse (Q7) can be reached from the experiment compartment by a door which may have leaked during the experiment. Note that the response time of Q7, compared with Q3, Q4 and Q5, is very quick. This may be explained by the way the doors open. The door in BHD 78 opens into the warehouse, while the door in BHD 71 opens into the experiment compartment, as is indicated in Figure 8. Due to the pressure in the experiment compartment, the door in BHD 78 will be forced open, while the door in BHD 71 will be forced 'more' closed.

In Table 5, the arrival time T_a, the maximum pressure P_{max} and time T_{max} are summarized.

Table 5 Quasi-static pressure measurement

Device	T_a [ms]	P_{max} [kPa]	T_{max} [s]
Q1	6.4	100	0.2
Q2	6.6	110	0.2
Q3	12.0	2	0.3
Q4	12.0	8.8	1.0
Q5	12.4	8.1	1.0
Q6	5.5	25.7	1.1
Q7	7.0	14	1.8

A comparison with theoretical values is only possible for Q1 and Q2, mounted in the experiment compartment. According to Baker (1983, Figure 3.15), a quasi-static pressure of 135 kPa will be found, based on 2 kg TNT and a compartment volume of 77 m^3. (The Weibull distribution leads to 160 kPa). Comparing this value (135 kPa) with the measured peak values of Q1 and Q2 (100 kPa and 110 kPa) shows a close resemblance.

Comparing the arrival time of device Q1 and Q2 with the arrival time of pressure transducers B1 and B2, as summarized in Table 3, also shows a close resemblance.

The remaining quasi-static pressure devices seem to have recorded reliable signals, although the signal-to-noise ratio is strongly influenced by the low pressures monitored.

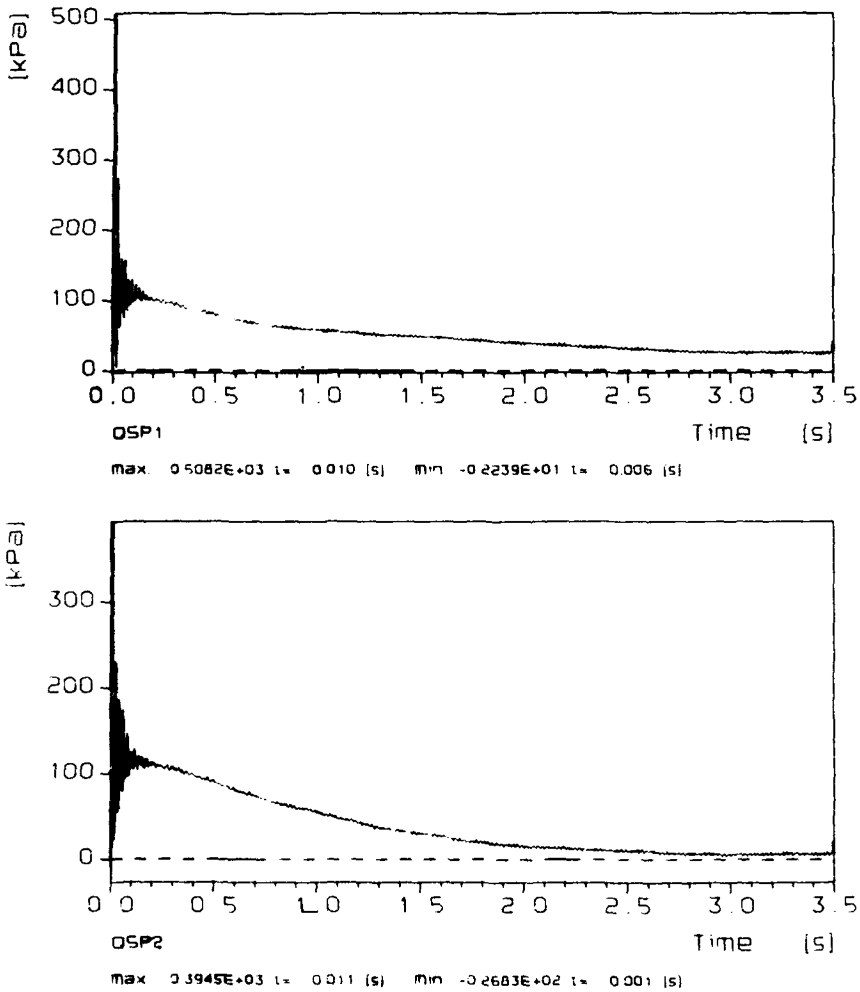


Figure 9 Quasi-static pressure signals Q1 and Q2 (experiment compartment)

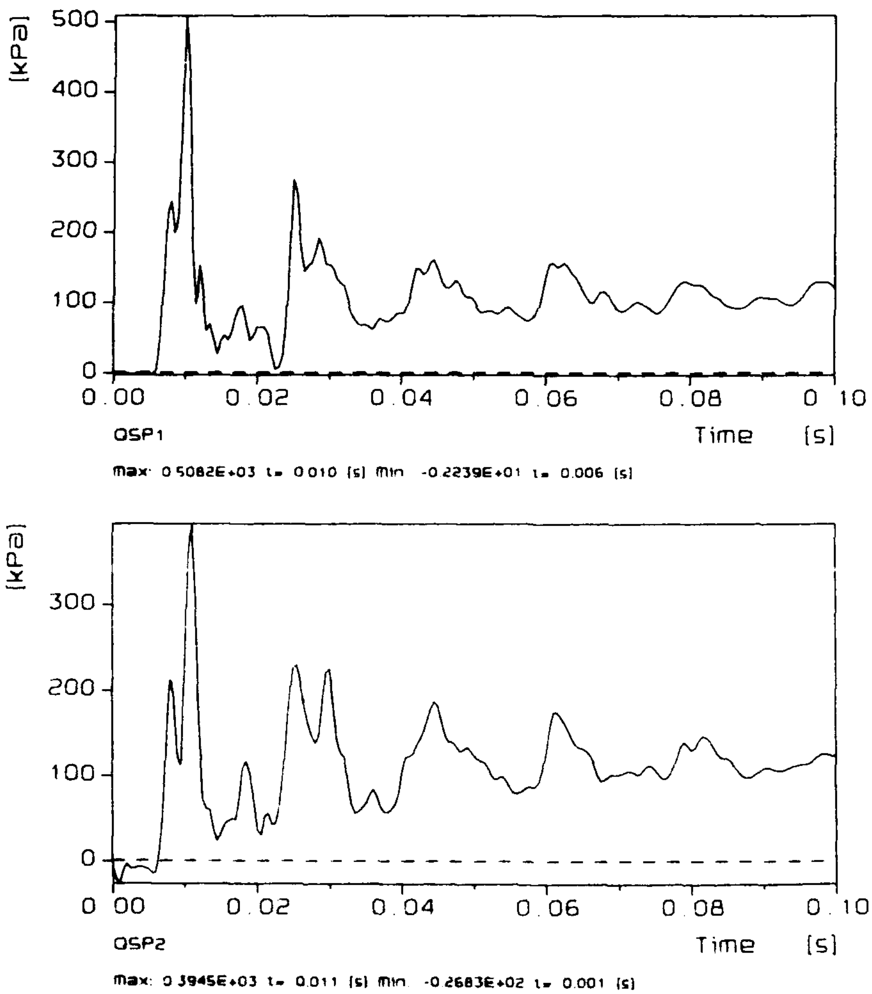


Figure 10 Quasi-static pressure signals Q1 and Q2 (experiment compartment)

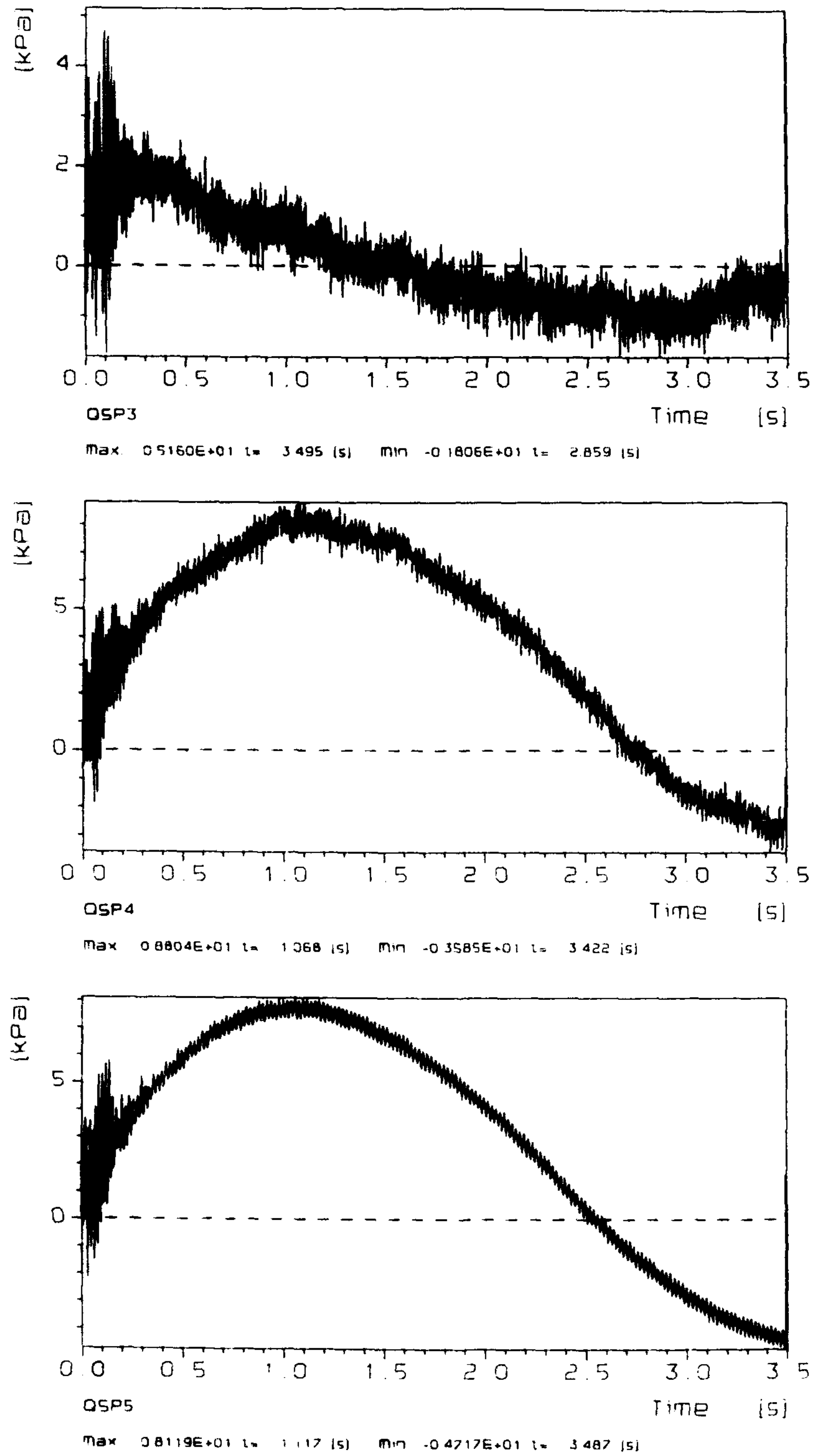
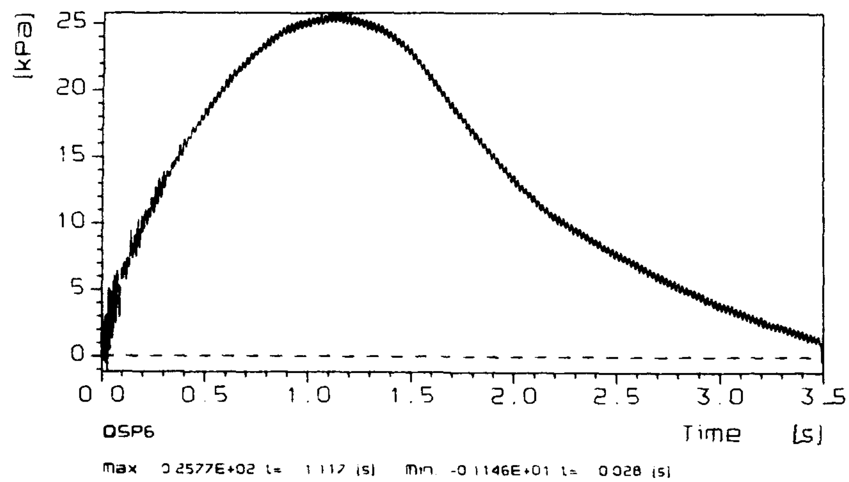


Figure 11 **Quasi-static pressure signals Q3, Q4 and Q5 (corporals' mess/sleeping compartment)**



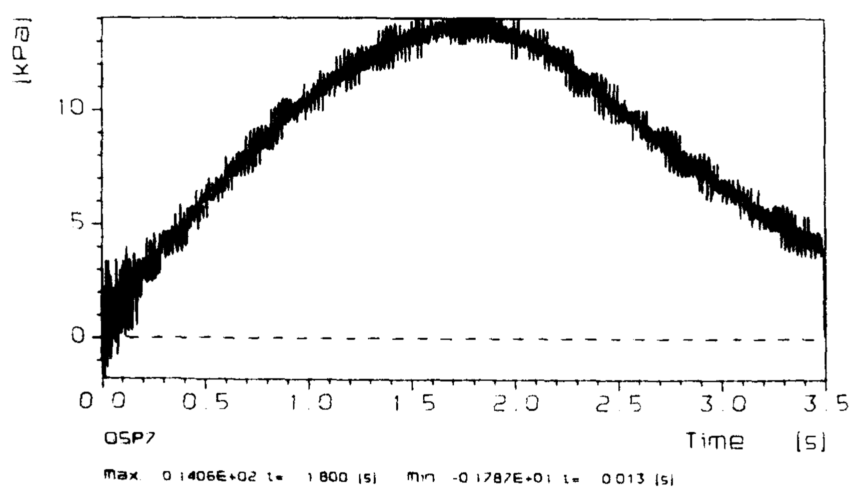


Figure 12 Quasi-static pressure signals Q6 (munition depository) and Q7 (warehouse)

5 STRAIN MEASUREMENTS

5.1 Position of the strain gauges

The strain was measured using 2% and 10% strain gauges in twenty-two positions (S1-S22) during the experiment. Some of the strain gauges were placed in pairs, opposite each other on either side of the wall.
The positions of the strain gauges are summarized in Tables 6-8 and shown schematically in Figures 13-16; a subdivision was used.

To describe and visualize the location of the strain gauges, the following notation is used:

: 2% strain gauge, single, front side

: 2% strain gauge, single, back side

d : 2% strain gauge, double, both sides

: 10% strain gauge, single, front side

: 10% strain gauge, single, back side

d : 10% strain gauge, double, both sides

The "front side" or "back side" description is related to the plane of view as shown in the figures.

Table 6 Position of the strain gauges on the hull (all in experiment compartment)

Device	Range	Height	Mounted on:
S1	2%	105.0 cm	Frame 74, SB
S2	2%	104.0 cm	Frame 74, PS

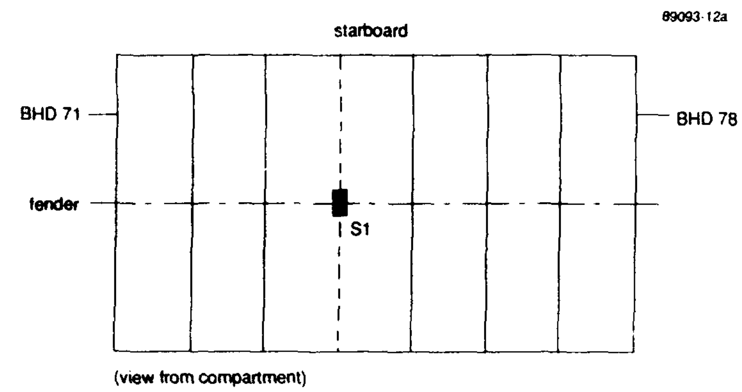


Figure 13 Schematic illustration of strain gauge position S1 (SB)

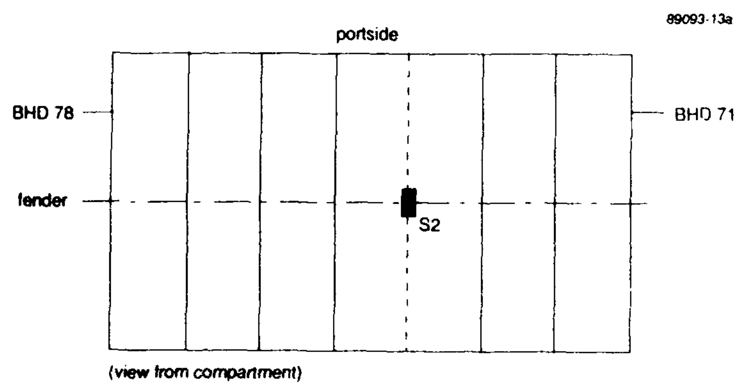


Figure 14 Schematic illustration of strain gauge position S2 (PS)

Table 7 Position of the strain gauges on BHD 71

Device	Range	Opposite	Height	Mounted on:
S3	10%	S22	80 cm(2)	centre door
S4(1)	10%	---	114 cm	wall, back side stiffener
S5	2%	S6	114 cm	10 cm beside stiffener
S6(1)	2%	S5	113 cm	10 cm beside S4
S7	10%	S8	30 cm	on stiffener
S8	10%	S7	30 cm	wall back side stiffener
S9(1)	2%	S10	30 cm	wall, 10 cm beside stiffener
S10(1)	2%	S9	30 cm	wall, 10 cm beside S8
S11	10%	S12	6 cm	wall, 10 cm beside stiffener
S12(1)	10%	S11	6 cm	wall
S13	2%	---	73 cm(3)	on stiffener
S22(1)	10%	S3	80 cm(2)	centre door

(1) in experiment compartment

(2) from bottom side door

(3) beneath ceiling (J-deck)

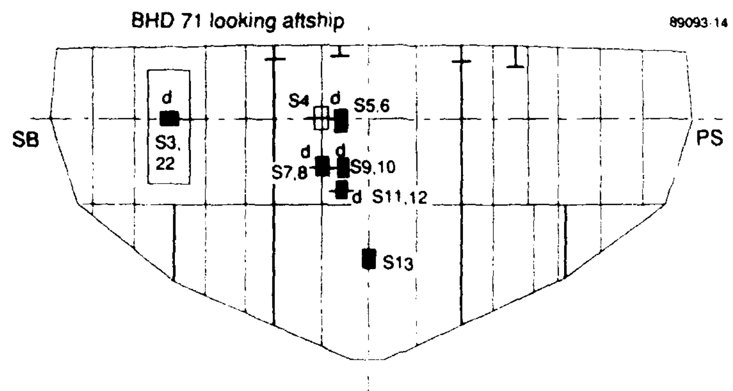


Figure 15 Schematic illustration of strain gauge positions on BHD 71

Table 8 Position of the strain gauges on ceiling and upper deck

Device	Range	Opposite	Mounting place:
S14	10%	S15	see S15, on deck
S15(1)	10%	S14	28 cm from BHD 78, 10 cm PS from CL
S16	10%	S17	see S17, on deck
S17(1)	10%	S16	101 cm from BHD 71, 135 cm from PS girder
S18	10%	S19	see S19, on deck
S19(1)	10%	S18	15 cm from BHD 71, 40 cm from PS girder
S20	10%	S21	see S21, on deck
S21	10%	S20	15 cm from BHD 71, 40 cm from SB girder

(1) in experiment compartment

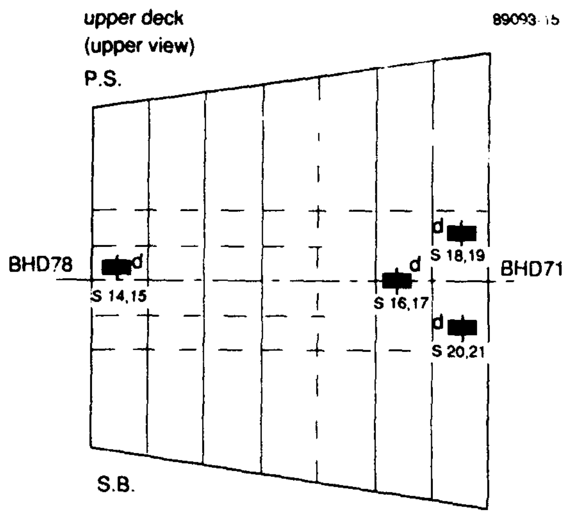


Figure 16 Schematic illustration of position of strain gauges on ceiling and upper deck (J-deck) of experiment compartment

5.2 Discussion of the strain measurements

The strain signals are shown on two different time-scales up to 300 ms in Figures 17-21, while in Figures 22-26, the signals are shown up to 2.5 s. Signals S11 and S18 are omitted due to a malfunction during the experiment. Opposite-mounted strain gauges are depicted in one figure, enabling a better understanding of the behaviour.

From these recordings it appears that some of the signals showed an elasto-plastic deformation (for instance, S3 and S22, S4, S7 and S16), while the other strain gauges only registered elastic deformations. Some of the latter signals showed, nevertheless, a permanent deformation which may be due to the elasto-plastic deformation of another part of the structure and cannot be regarded as offset or drift. Consider, for instance, couple S7 and S8 in more detail. Note that S7 was mounted on a stiffener whereas S8 was mounted on the wall. S7 shows a permanent elasto-plastic deformation, i.e. the stiffener was deformed during the experiment. This deformation will however also act on the wall, leading to a permanent deformation as registered by S8.

From the figures presenting two opposite-mounted strain gauges, it appears that some of the responses were 'in-phase' (S5 and S6, S9 and S10, S14 and S15) whereas others were in 'anti-phase' (S7 and S8). This different response can be explained as follows: the plate is part of the girder and acts as one of the flanges. Consequently, a bending vibration in the girder is observed as an 'in-phase' vibration in the plate near the girder.

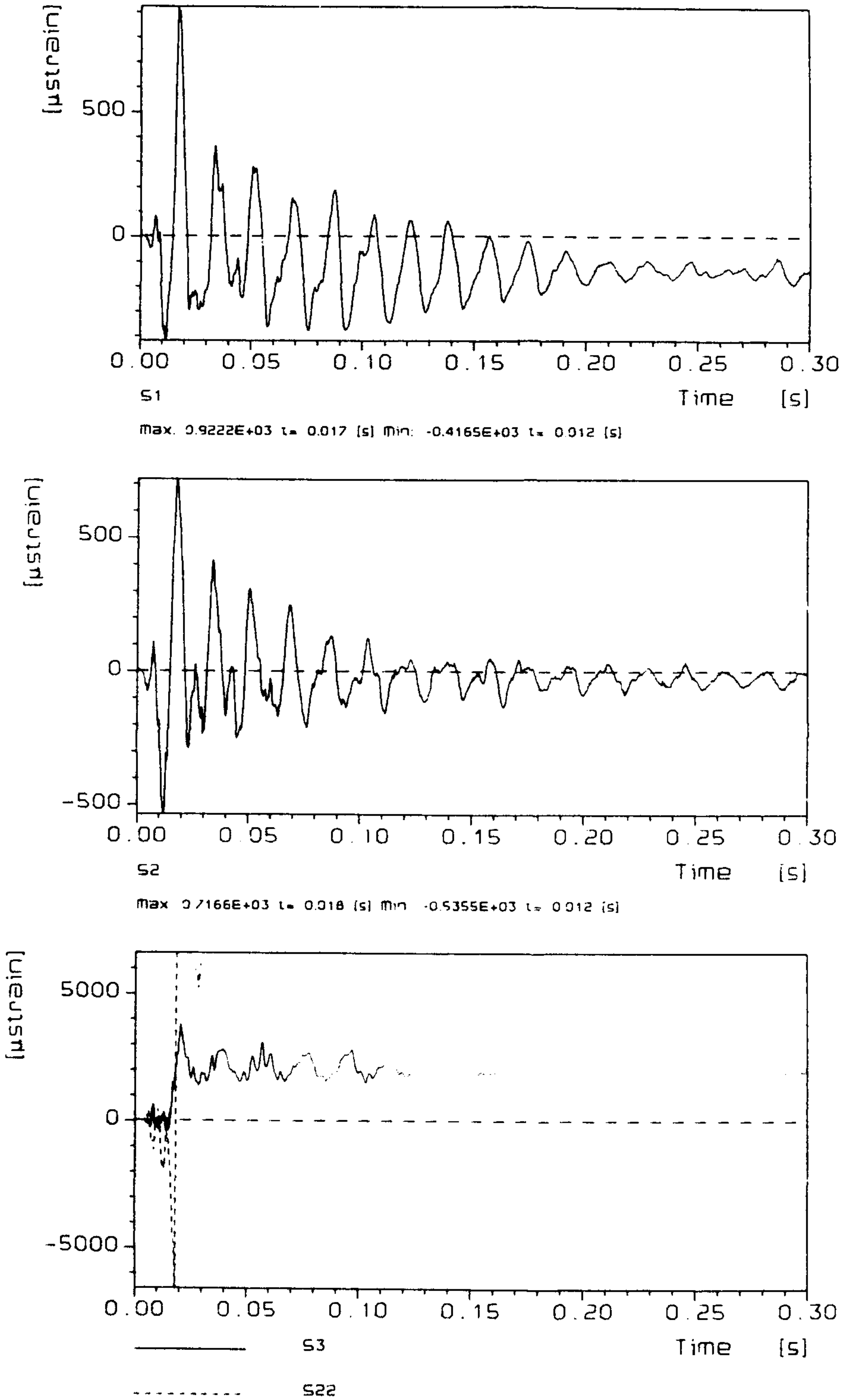


Figure 17 **Strain gauge response S1, S2 (experiment compartment), S3 and S22 (BHD 71) (300 ms base)**

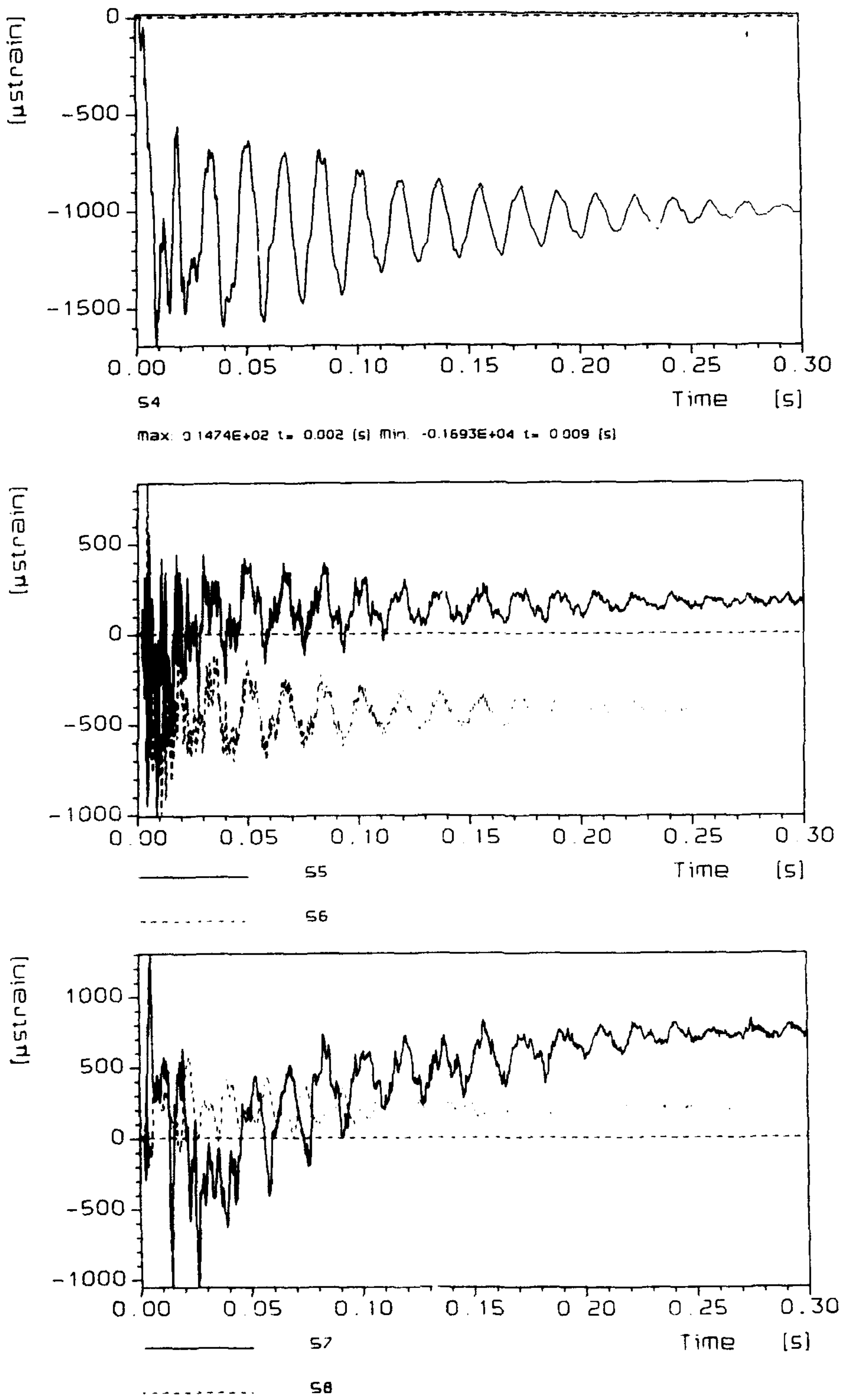


Figure 18 Strain gauge response S4, S5 and S6, S7 and S8 (BHD 71) (300 ms base)

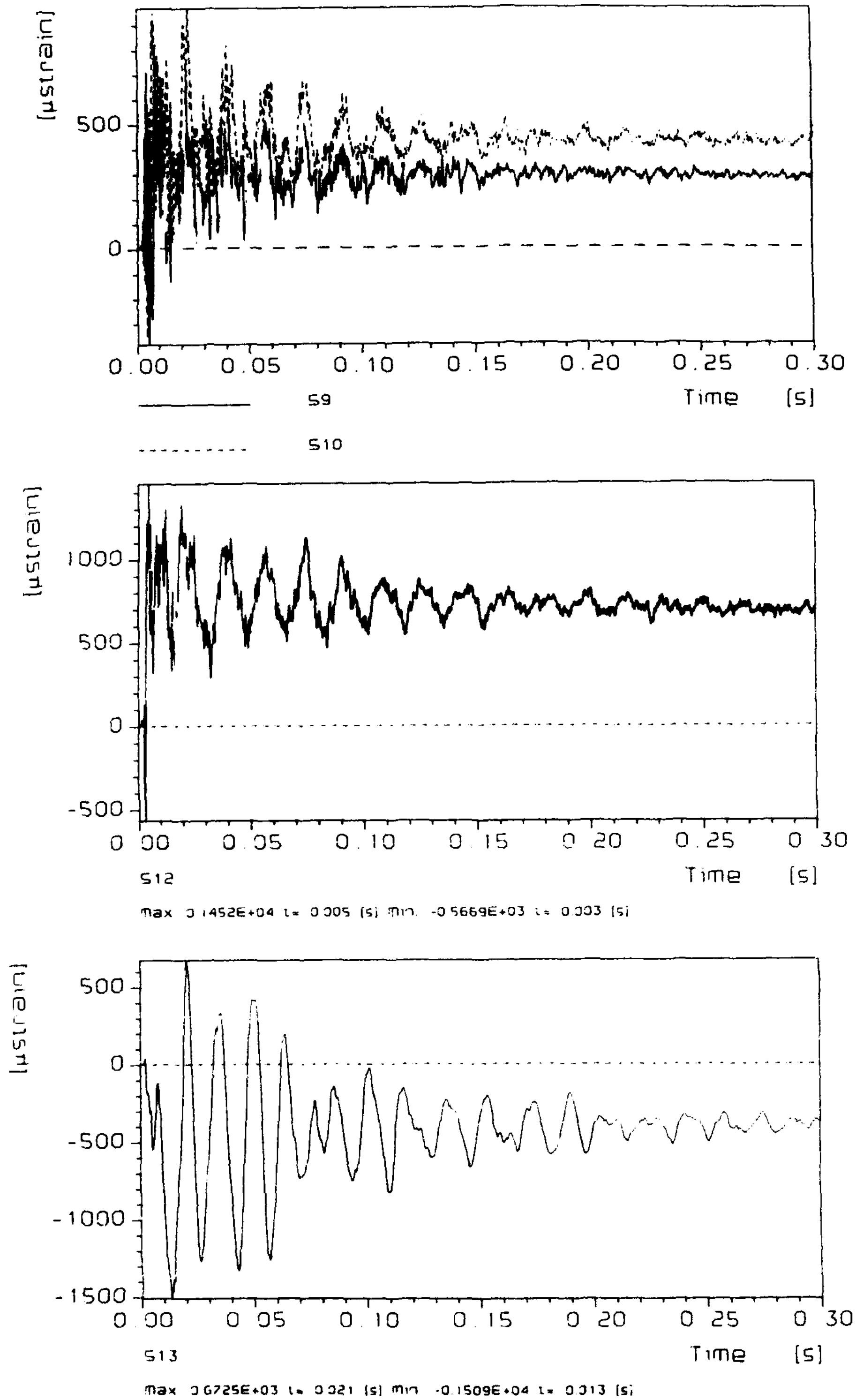


Figure 19 Strain gauge response S9 and S10, S12, S13 (BHD 71) (300 ms base)

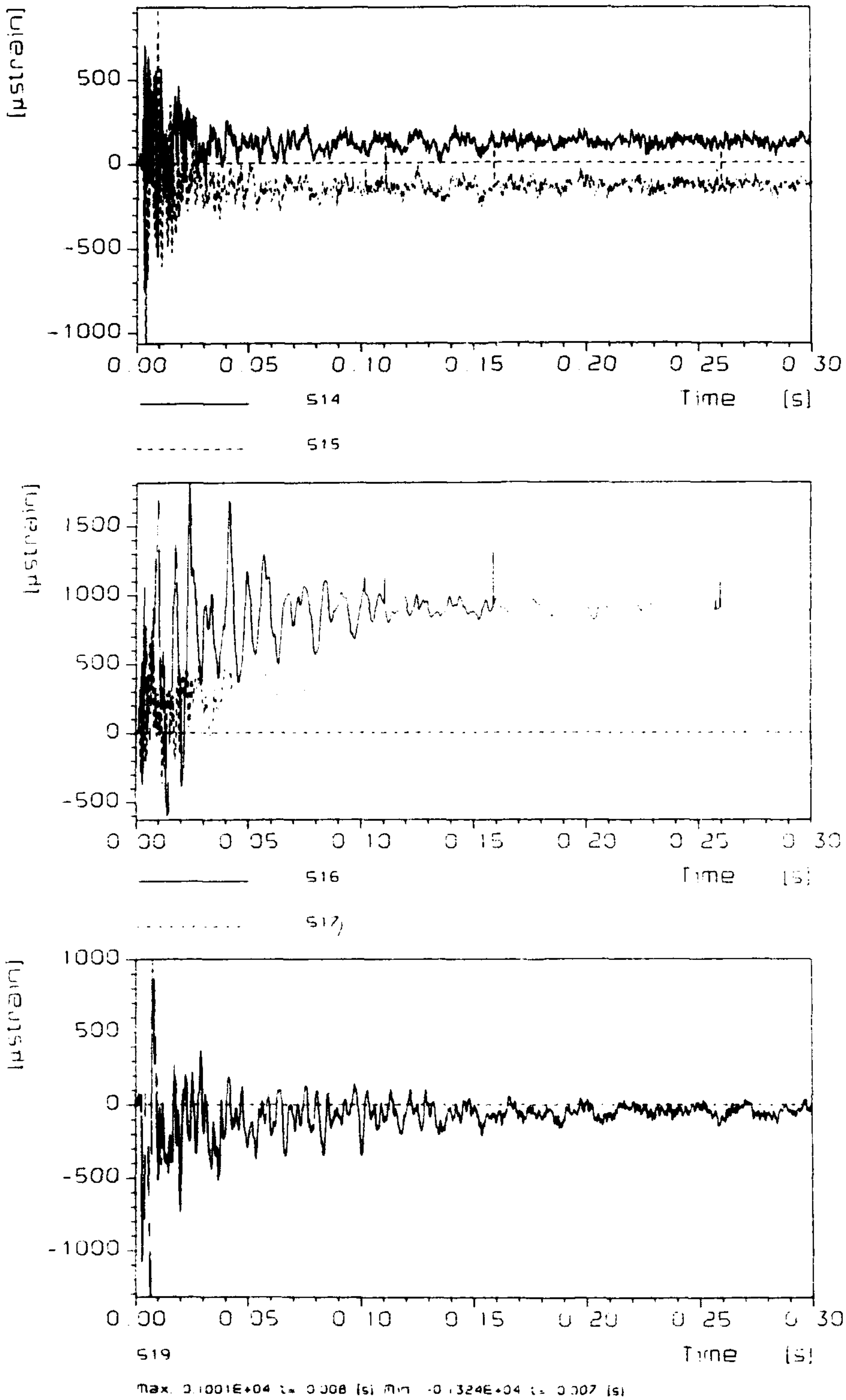


Figure 20 Strain gauge response S14 and S15, S16 and S17, S19 (Ceiling/upper deck) (300 ms base)

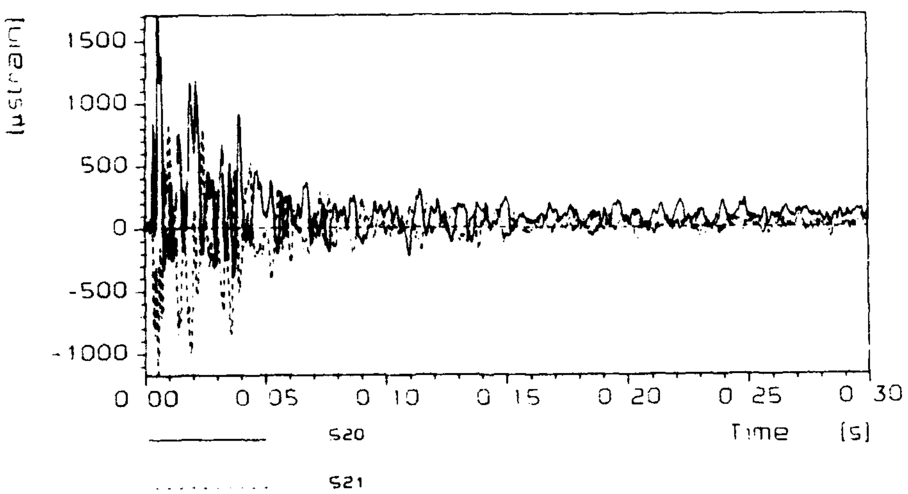


Figure 21 Strain gauge response S20 and S21 (Ceiling/upper deck) (300 ms base)

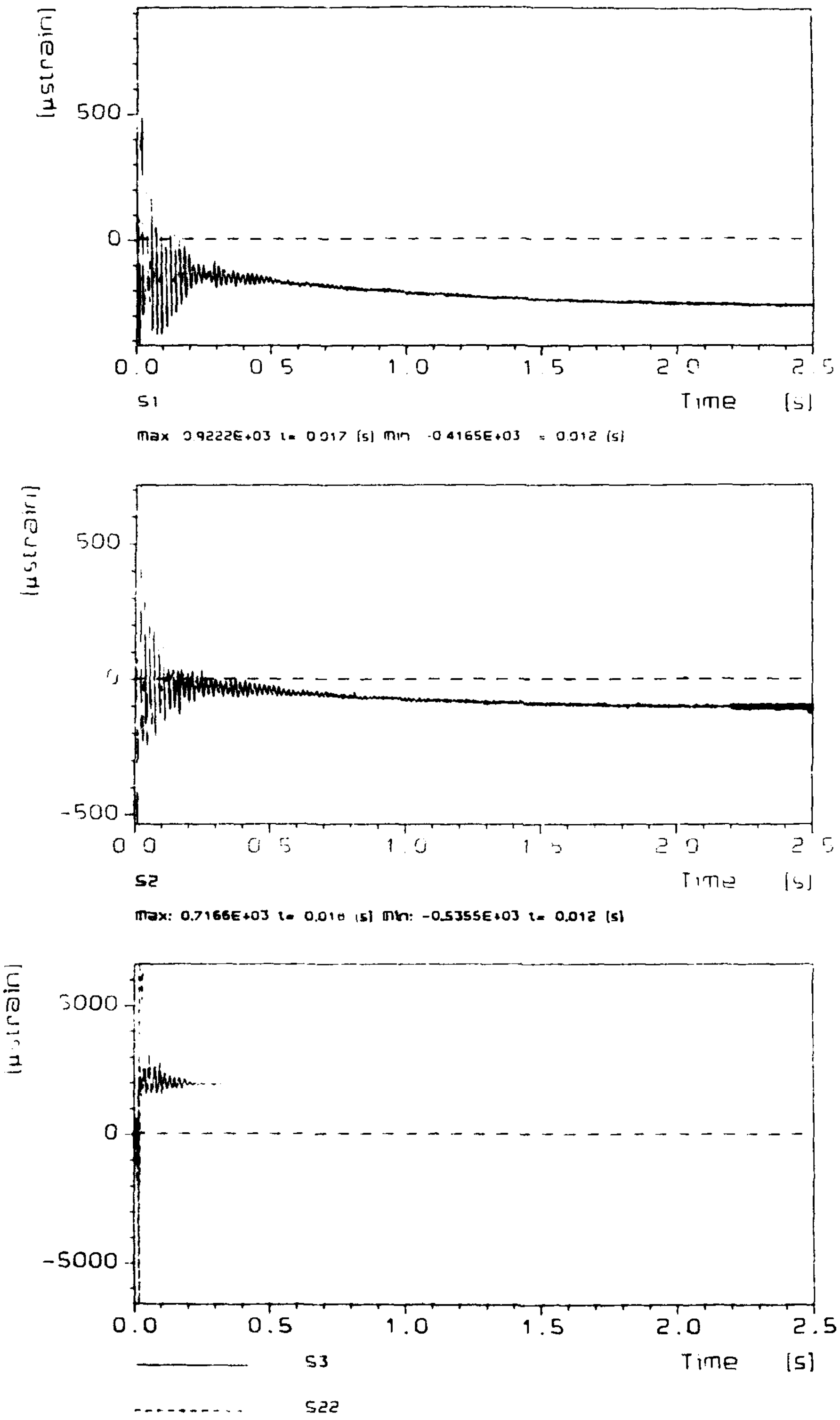


Figure 22 Strain gauge response S1, S2 (experiment compartment), S3 and S22 (BHD 71) (2.5 s base)

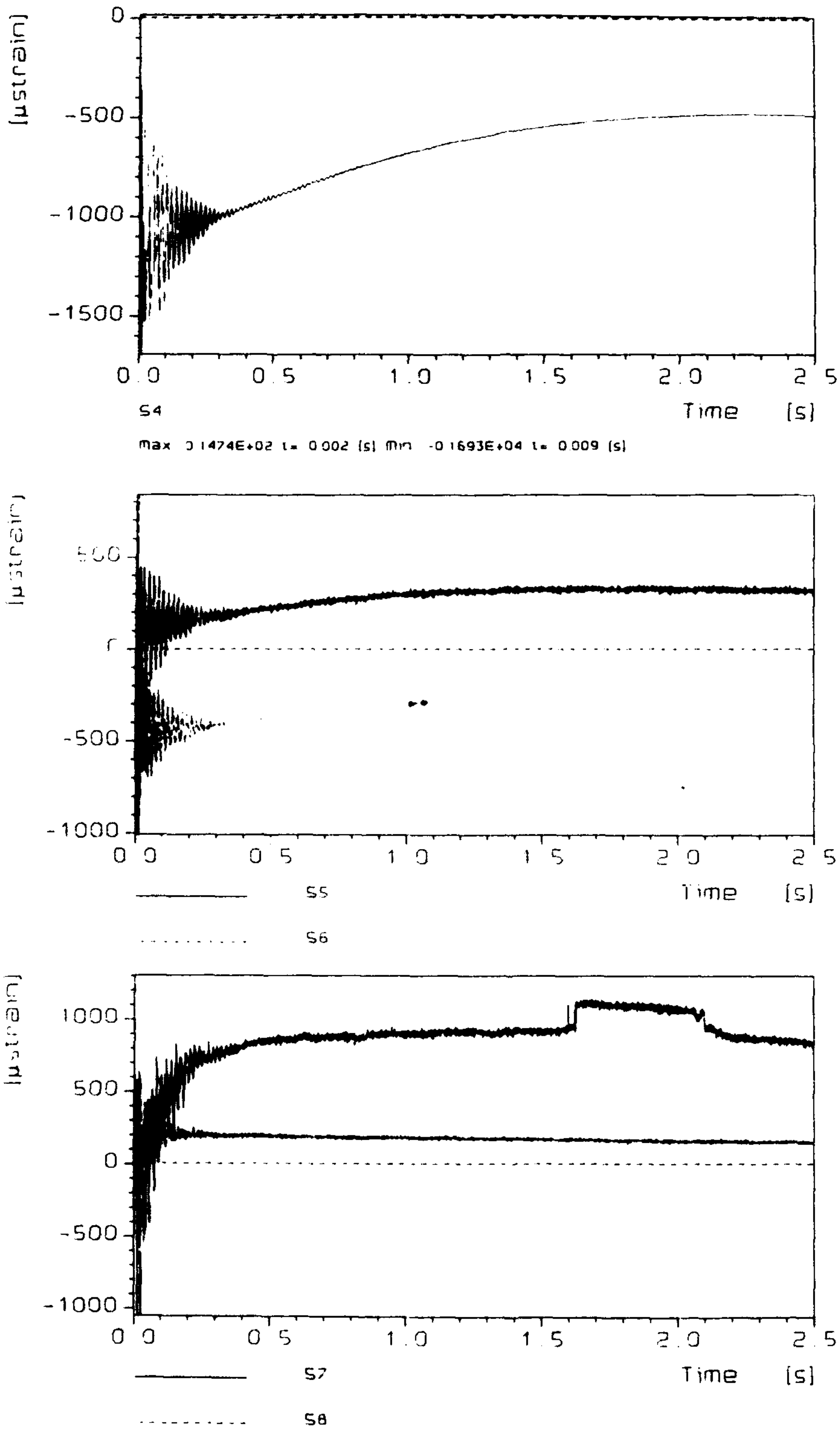


Figure 23 Strain gauge response S4, S5 and S6, S7 and S8 (BHD 71) (2.5 s base)

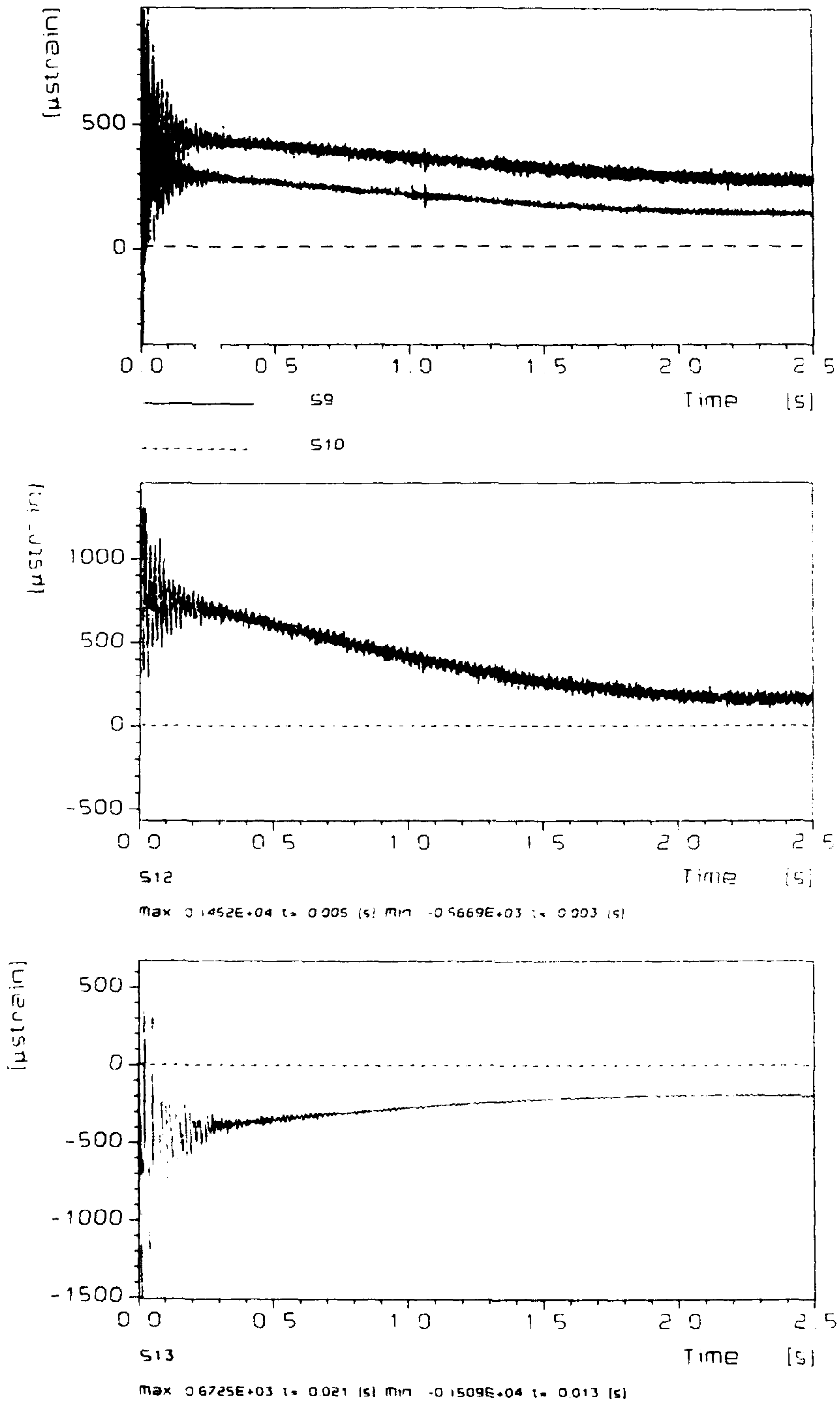


Figure 24 Strain gauge response S9 and S10, S12, S13 (BHD 71) (2.5 s base)

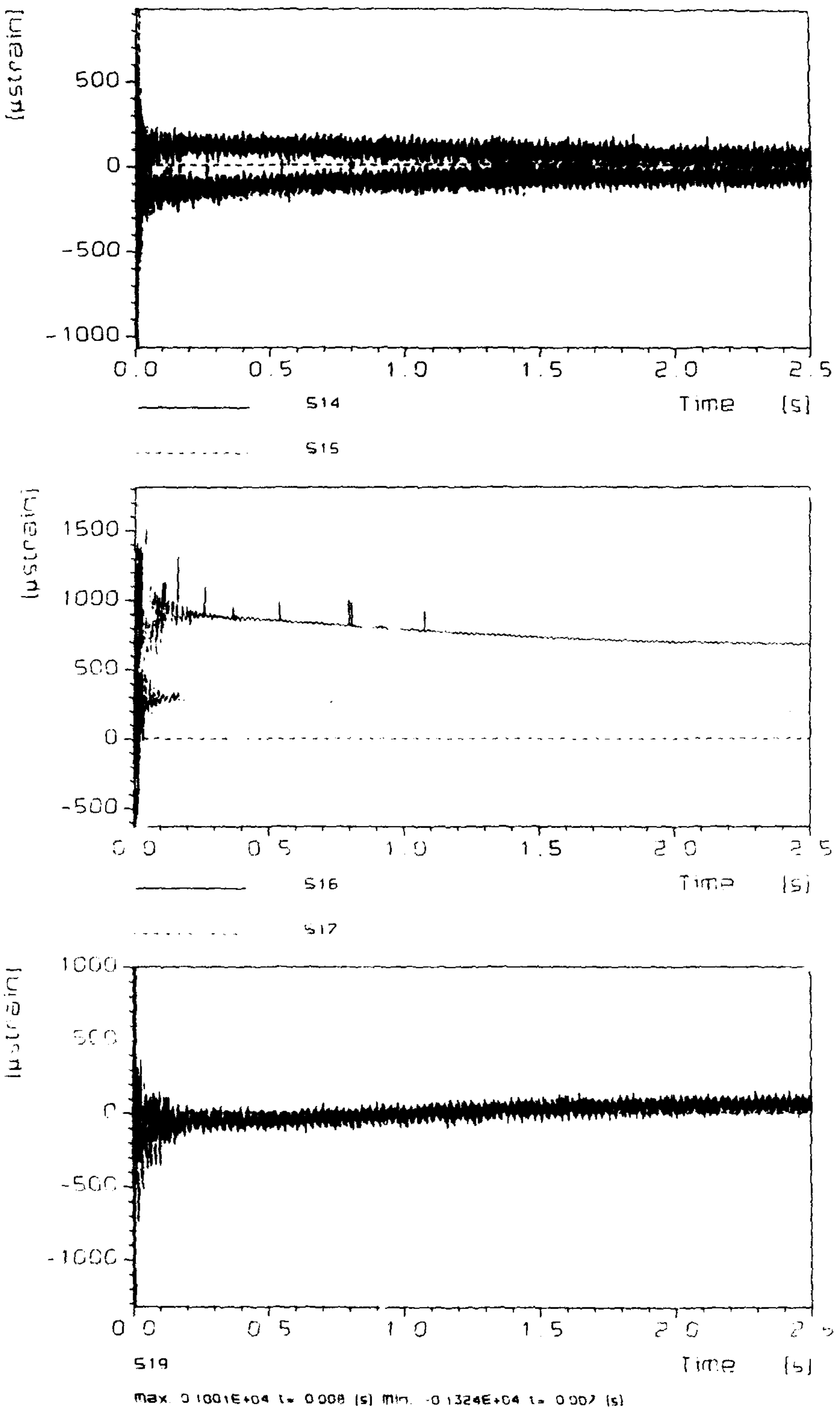


Figure 25 Strain gauge response S14 and S15, S16 and S17, S19 (Ceiling/upper deck) (2.5 s base)

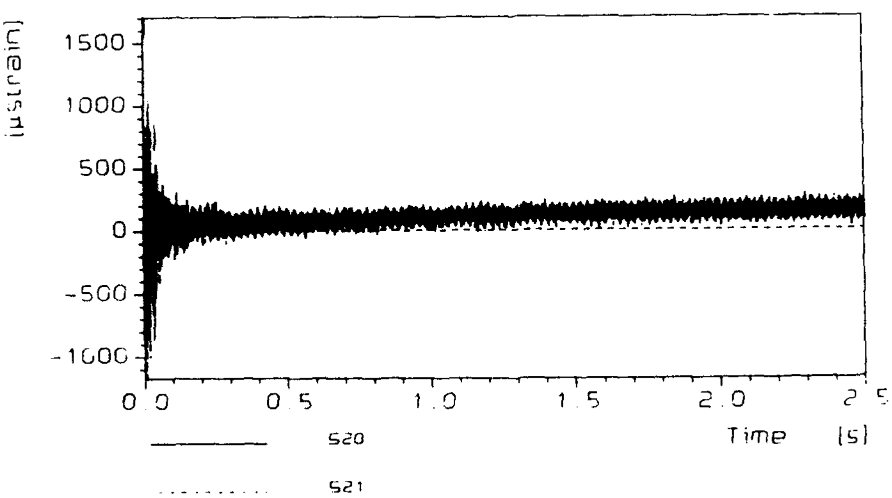


Figure 26 Strain gauge response S20 and S21 (Ceiling/upper deck) (2.5 s base)

6 ACCELERATION MEASUREMENTS

6.1 Position of the accelerometers

During the experiments in the crew aft sleeping compartment, seven accelerometers were used, mounted on the H and J deck, respectively. The location of these accelerometers are summarized in Table 9 and shown schematically in Figures 27 and 28. In these figures, the direction of sensitivity of the transducer is denoted by the length axis of the block ■.

Table 9 Position of the accelerometers

Device	Mounting position		
A1(1)			108 cm beneath ceiling J-deck on CL stiffener
A2	ceiling	J-deck	281 cm from BHD 78, 146 cm SB from CL
A3	floor	J-deck	281 cm from BHD 78, 146 cm SB from CL
A4	ceiling	J-deck	263 cm from BHD 71, on SB girder
A5	ceiling	J-deck	74 cm from BHD 45, on PS girder
A6	floor	J-deck	75 cm from BHD 45
A7(1)			111 cm above floor J-deck on stiffener

(1) vertical direction

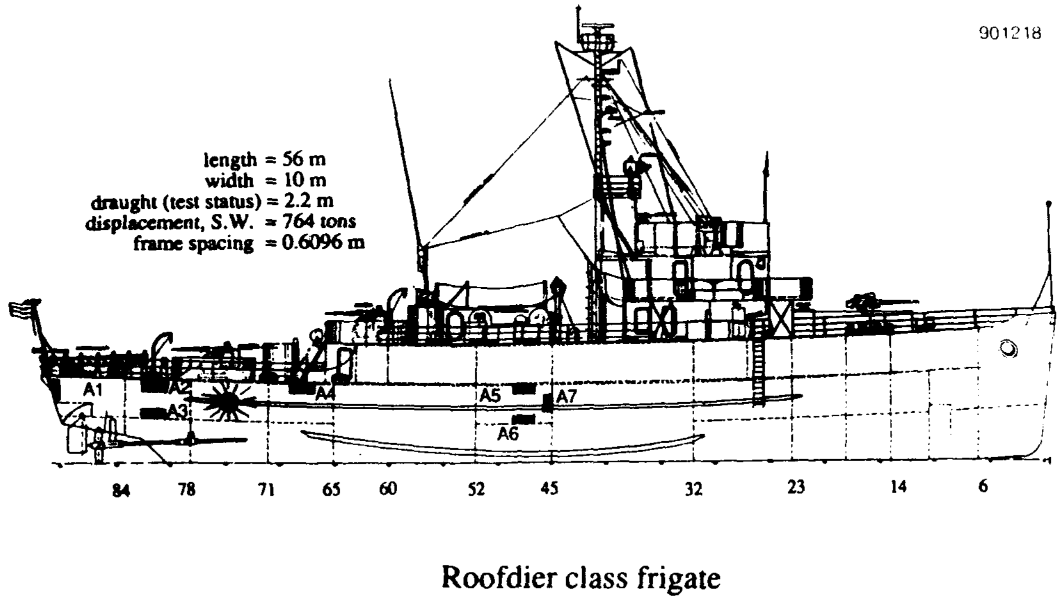


Figure 27 Schematic illustration of the positions of the accelerometers

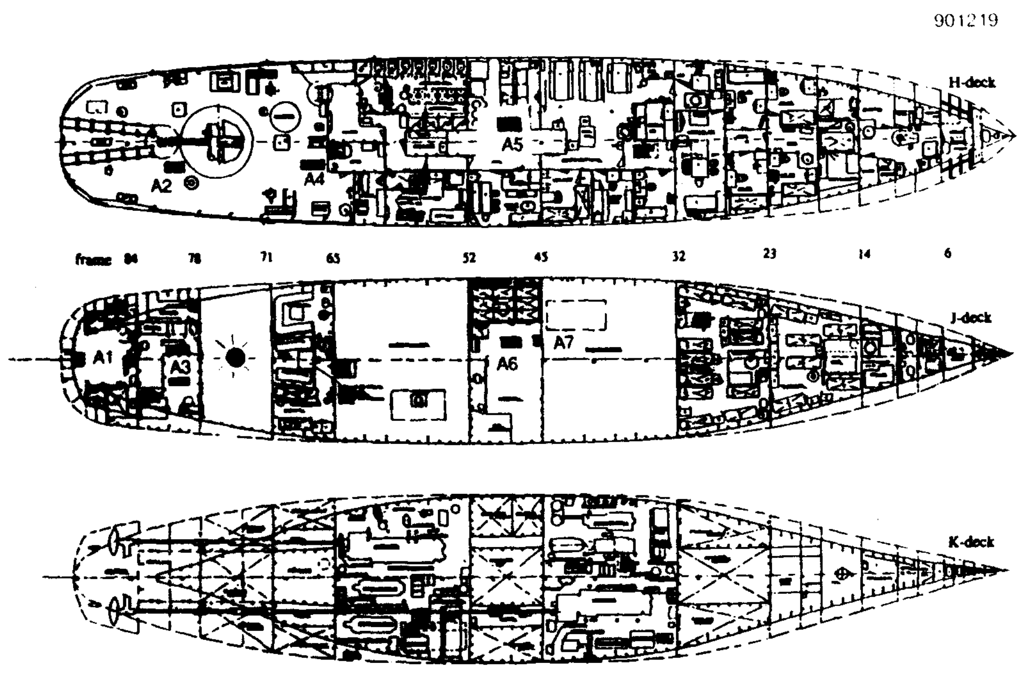


Figure 28 Schematic illustration of the positions of the accelerometers

6.2 Discussion of the acceleration measurements

The acceleration measurement results are shown in Figures 29-35. A distortion of 50 Hz has been removed from these signals. Additionally, a third order low pass Butterworth filter (1.5 kHz) was used. Integration of the signals with respect to the time, results in the velocity and displacement signals, which are also shown in these figures. Drift correction was performed for a number of signals, as is indicated in the legends by the signals. It is obvious that these (rather ad hoc) signal analysis techniques strongly influence the presented velocity and displacement signals.

Additionally, the shock spectra are presented in Figures 36-42. The positive and negative residual shock spectra are identical because damping was omitted.

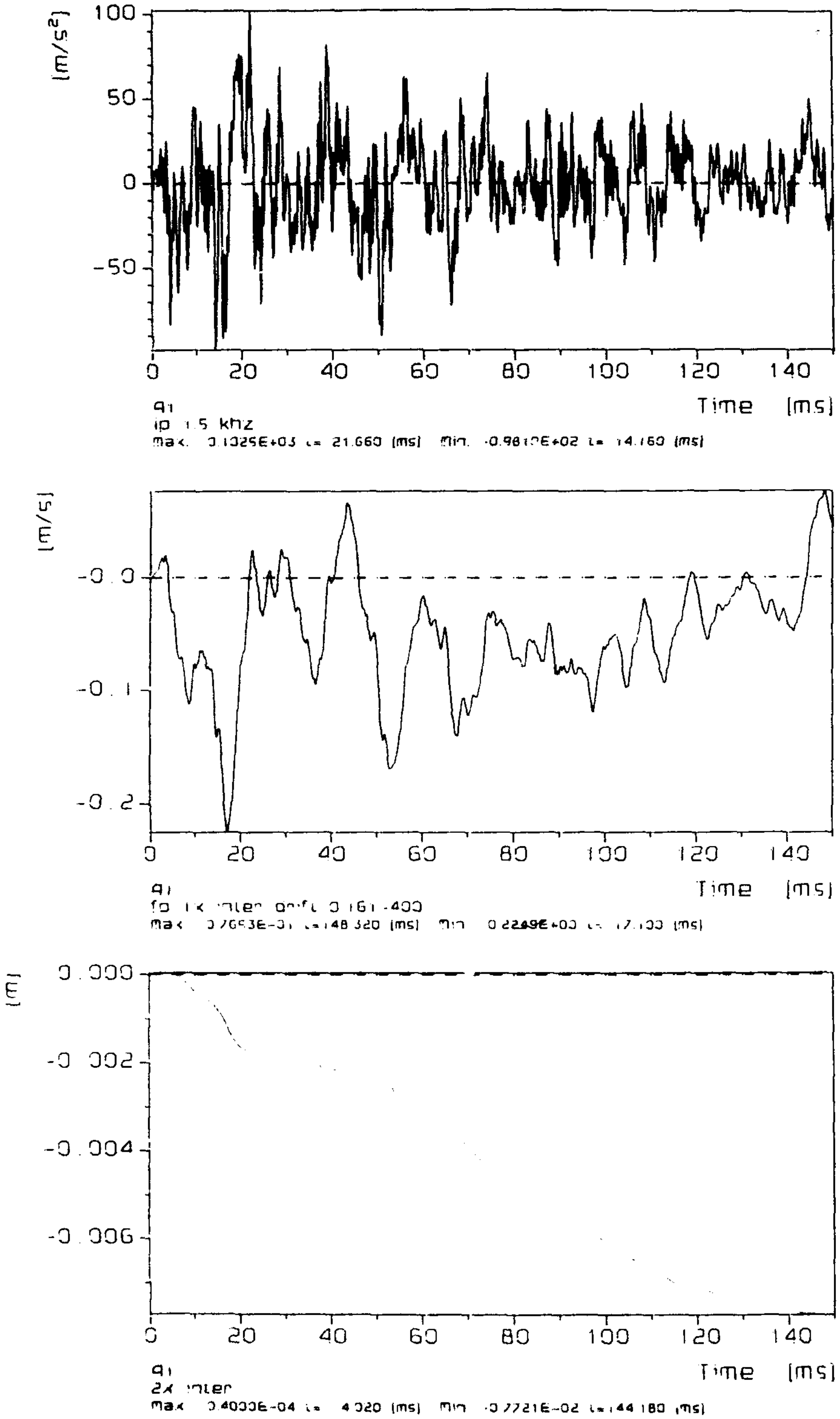


Figure 29 Accelerometer A1

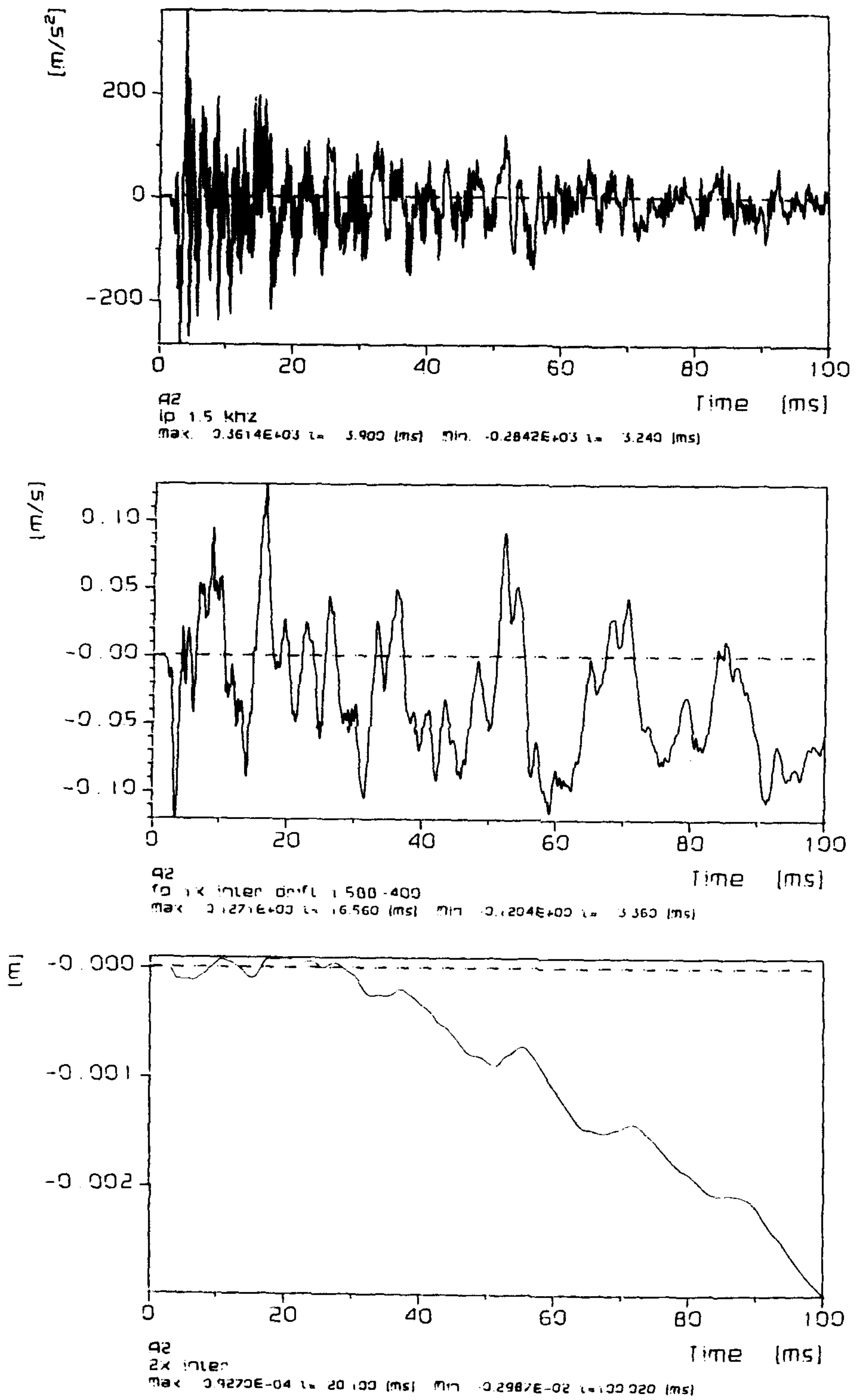


Figure 30 Accelerometer A2

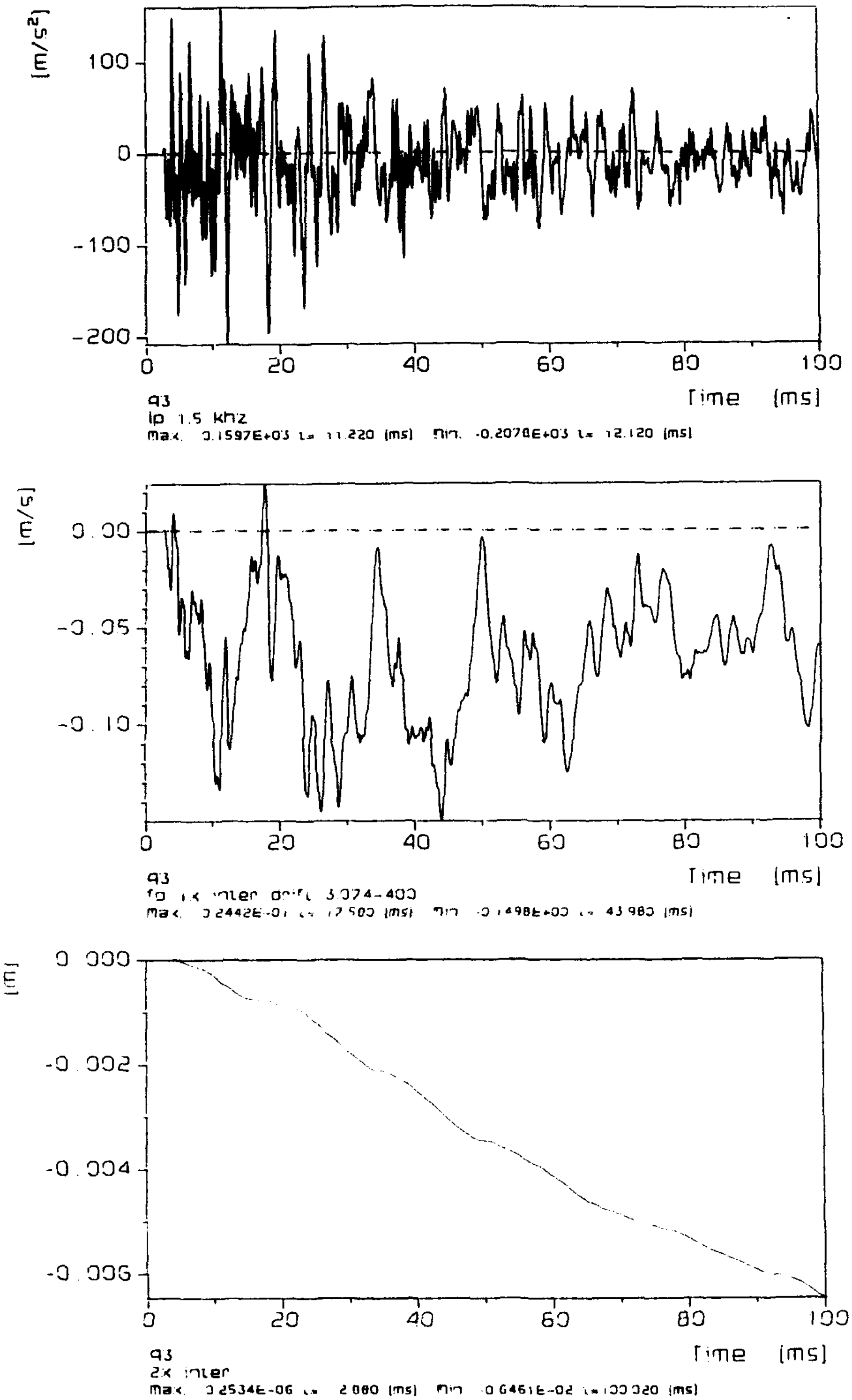


Figure 31 Accelerometer A3

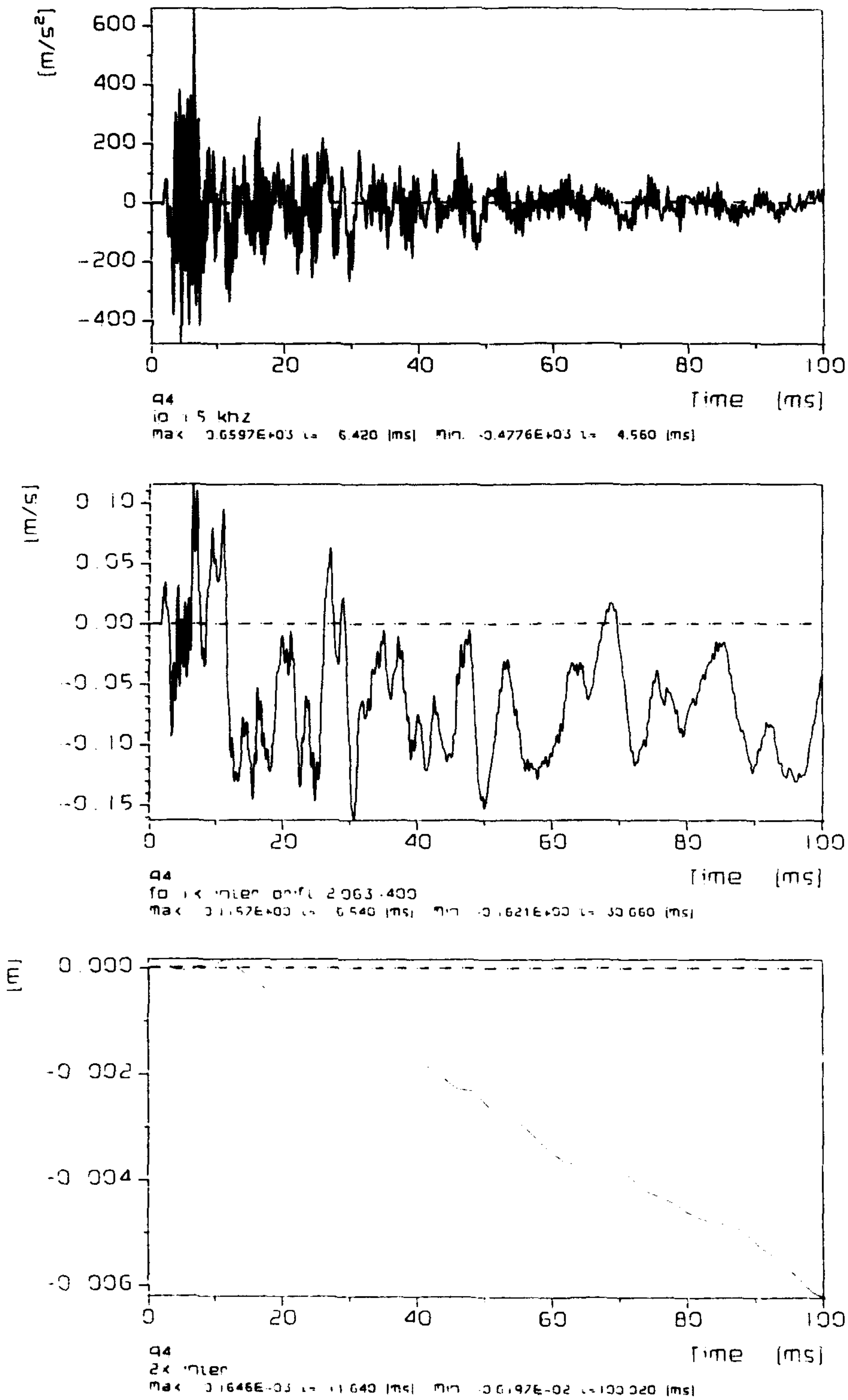


Figure 32 Accelerometer A4

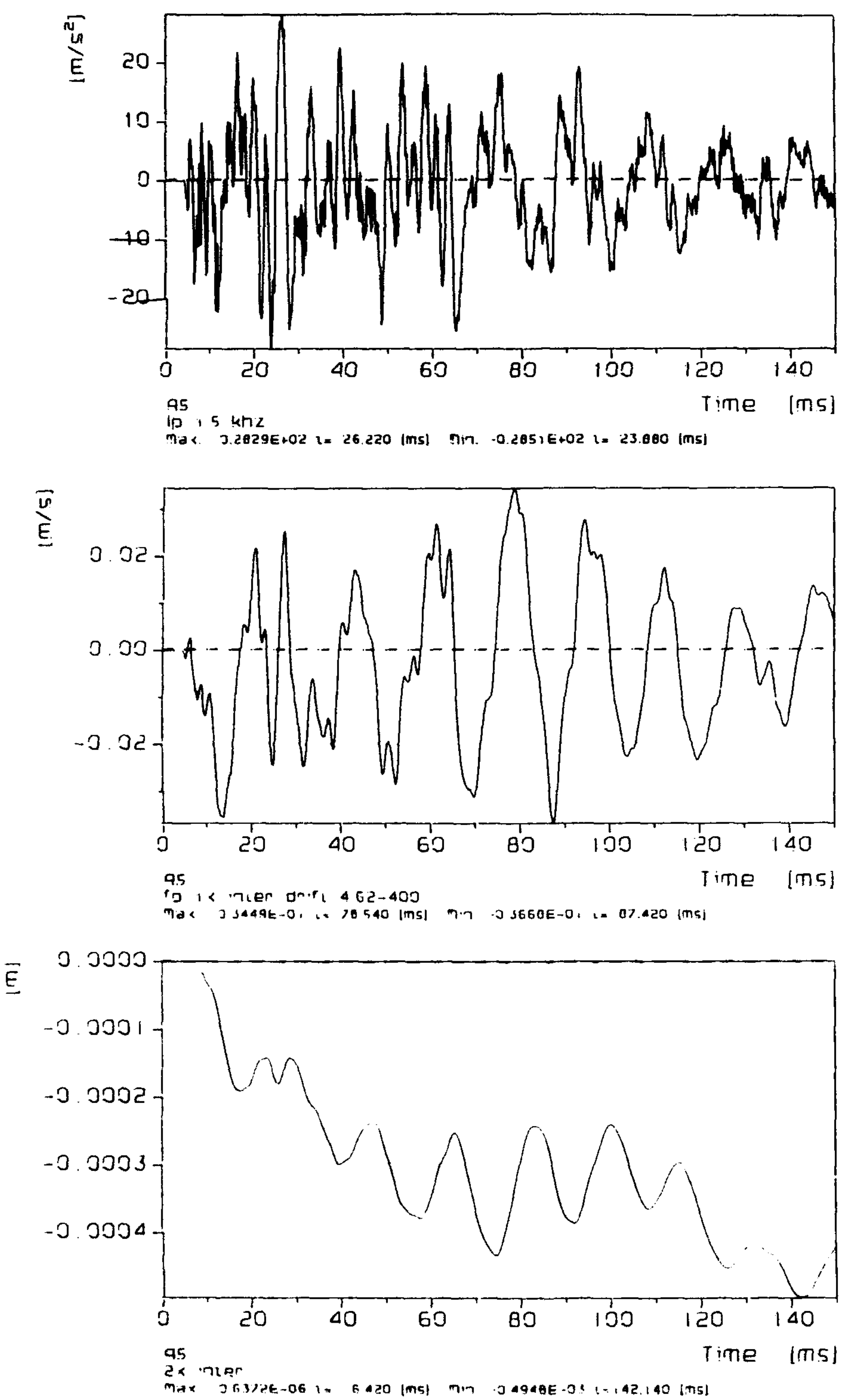


Figure 33 **Accelerometer A5**

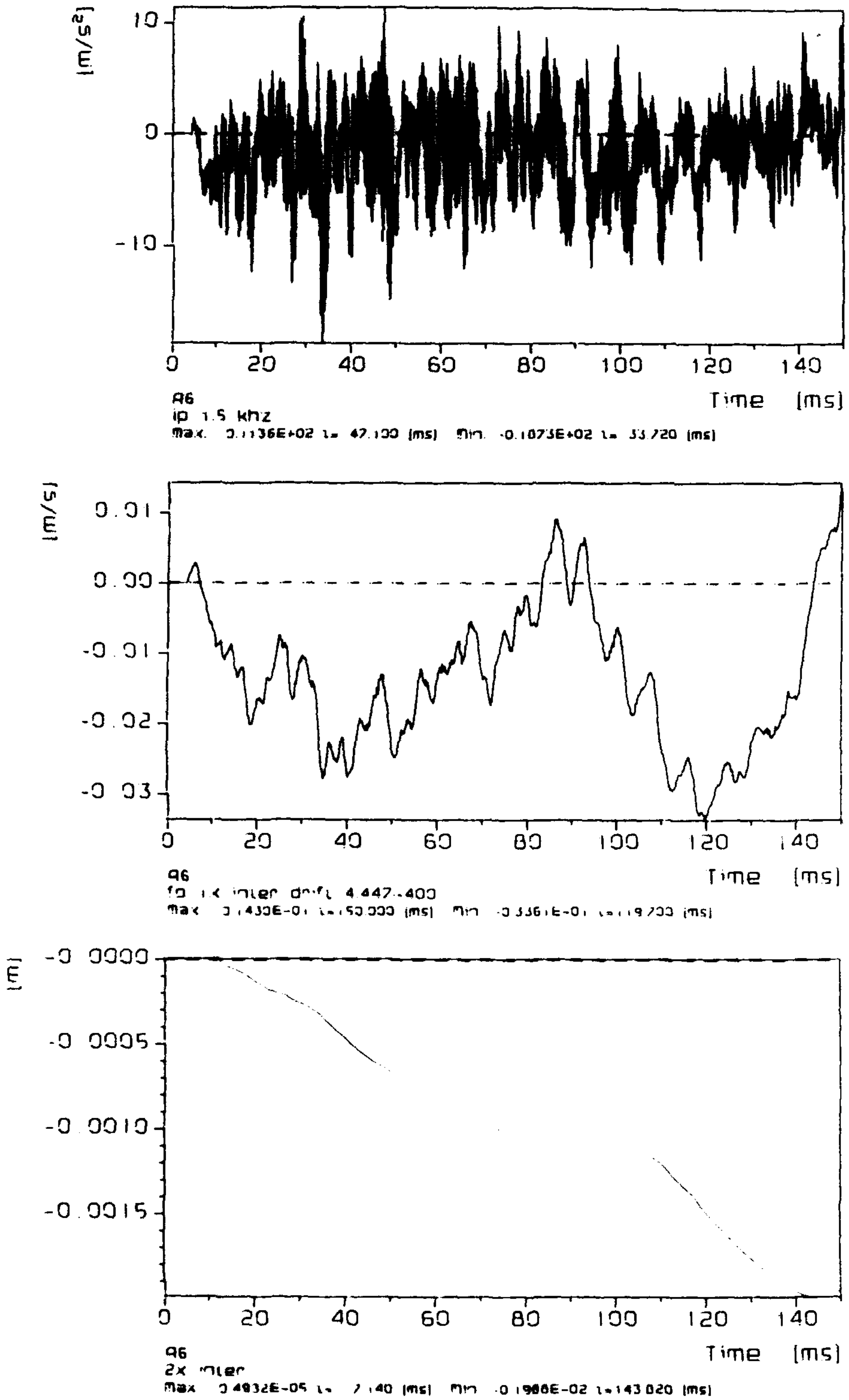


Figure 34 Accelerometer A6

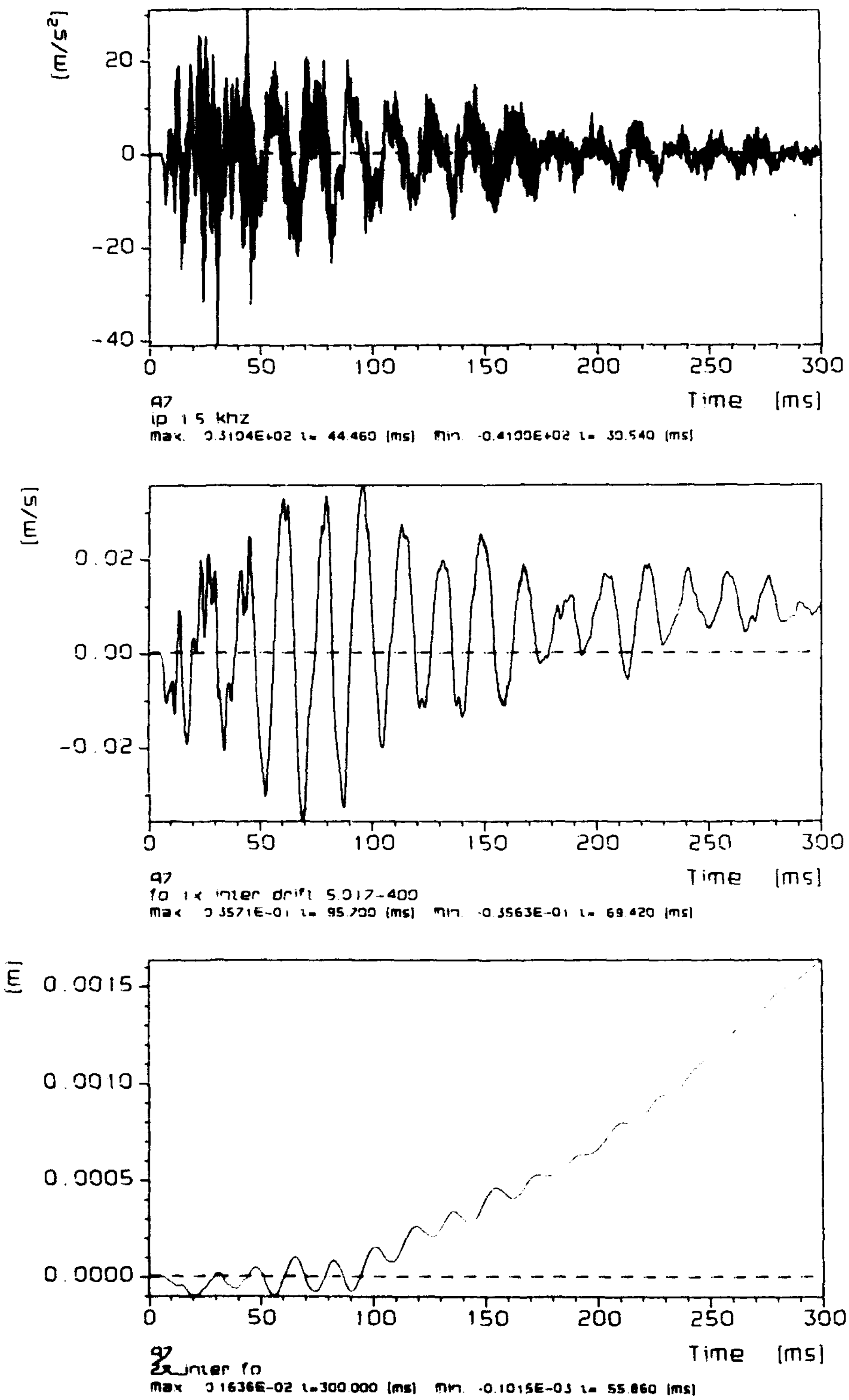


Figure 35 Accelerometer A7

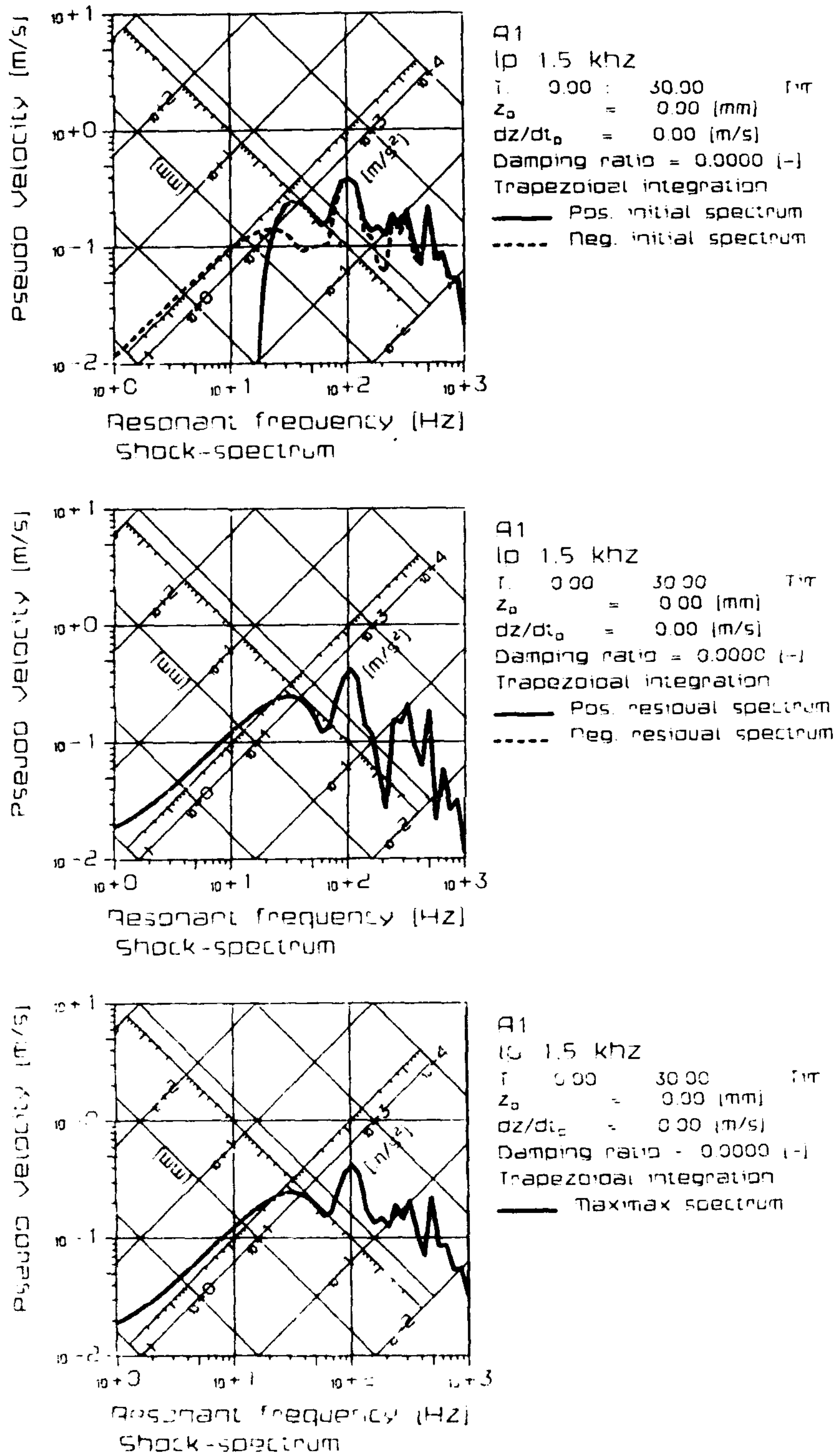


Figure 36 Shock spectra of accelerometer A1

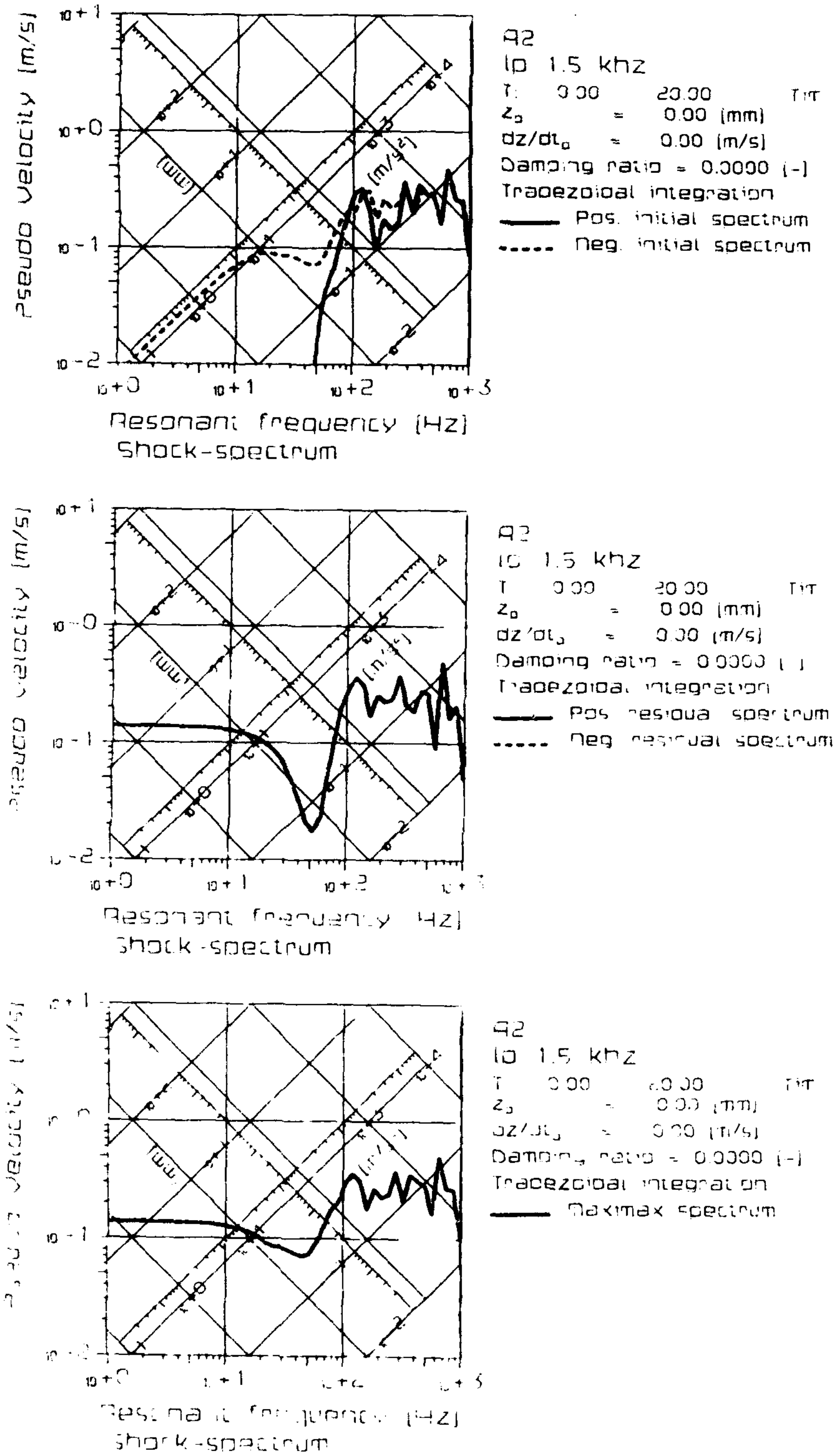


Figure 37 Shock spectra of accelerometer A2

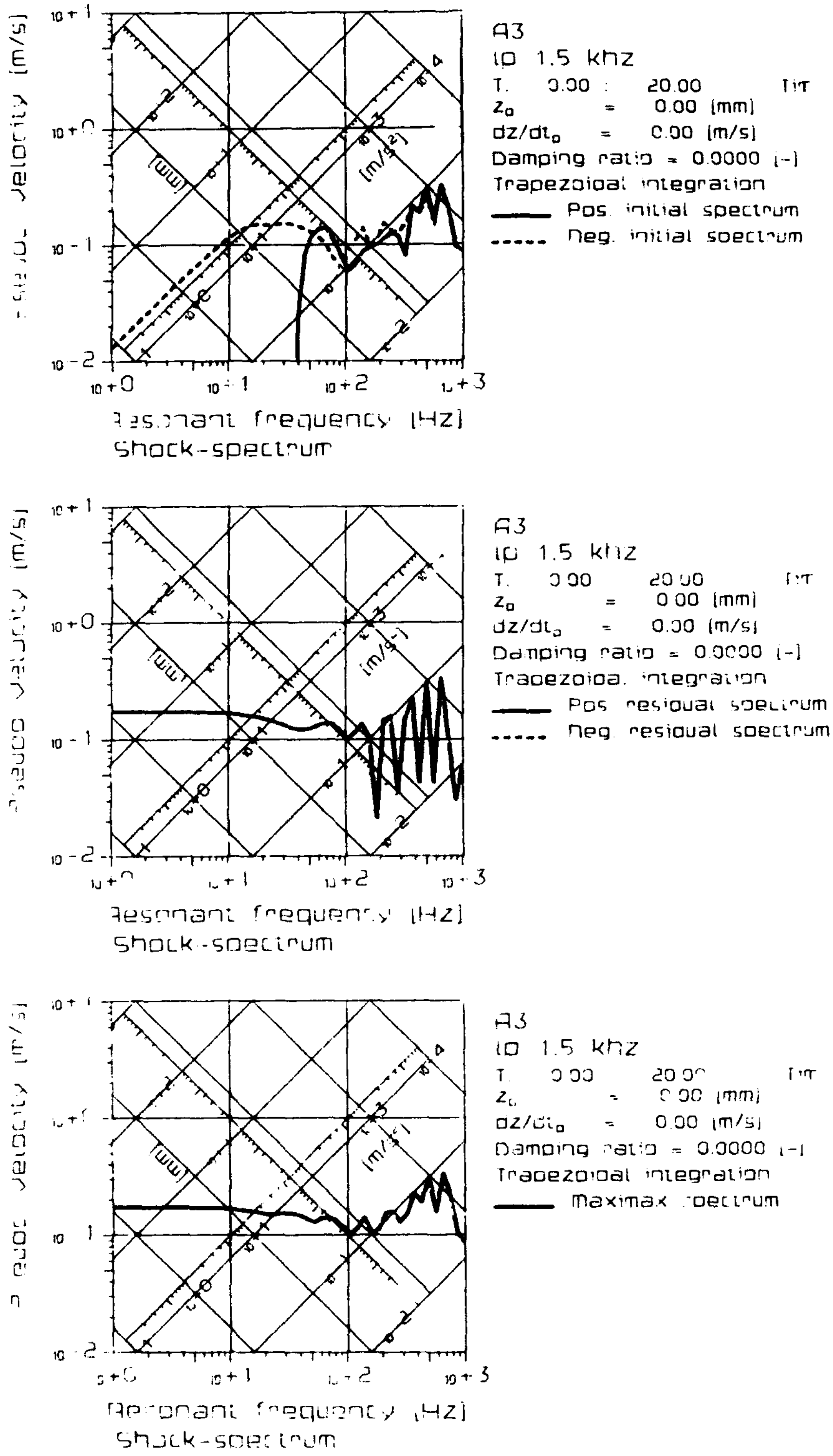
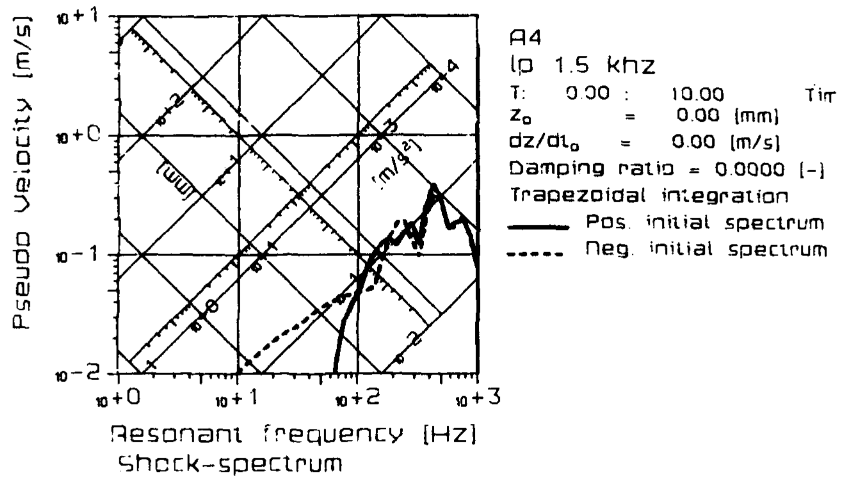
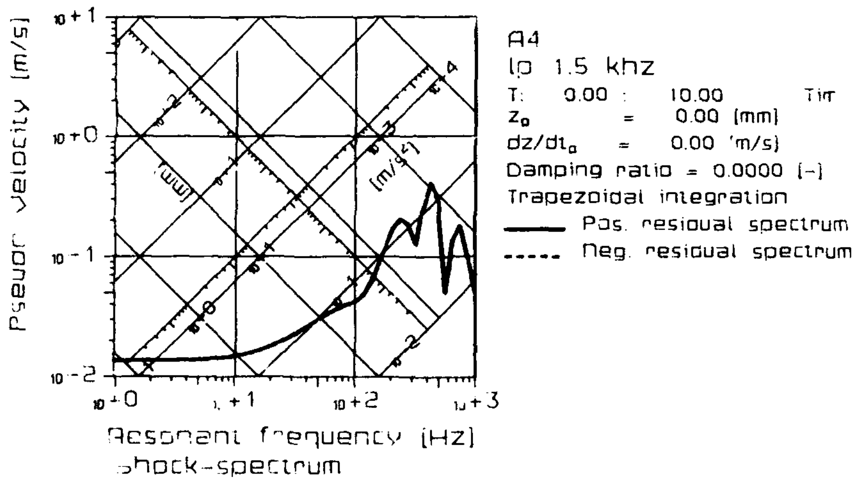


Figure 38 Shock spectra of accelerometer A3





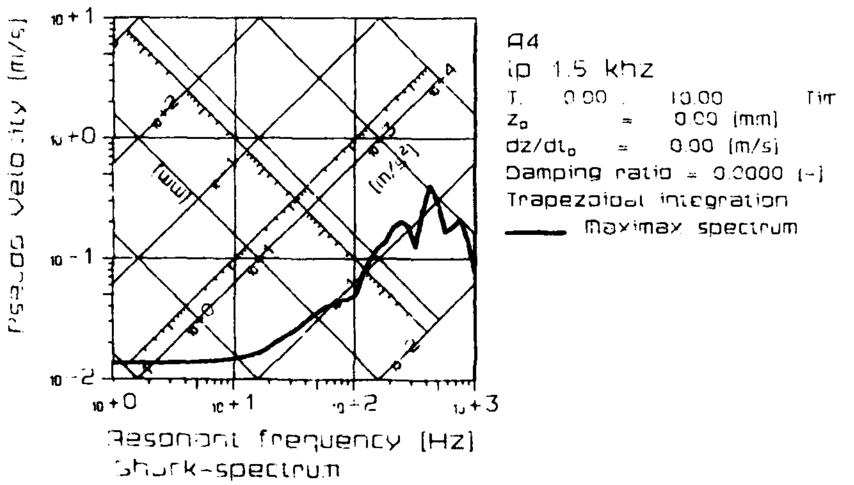


Figure 39 Shock spectra of accelerometer A4

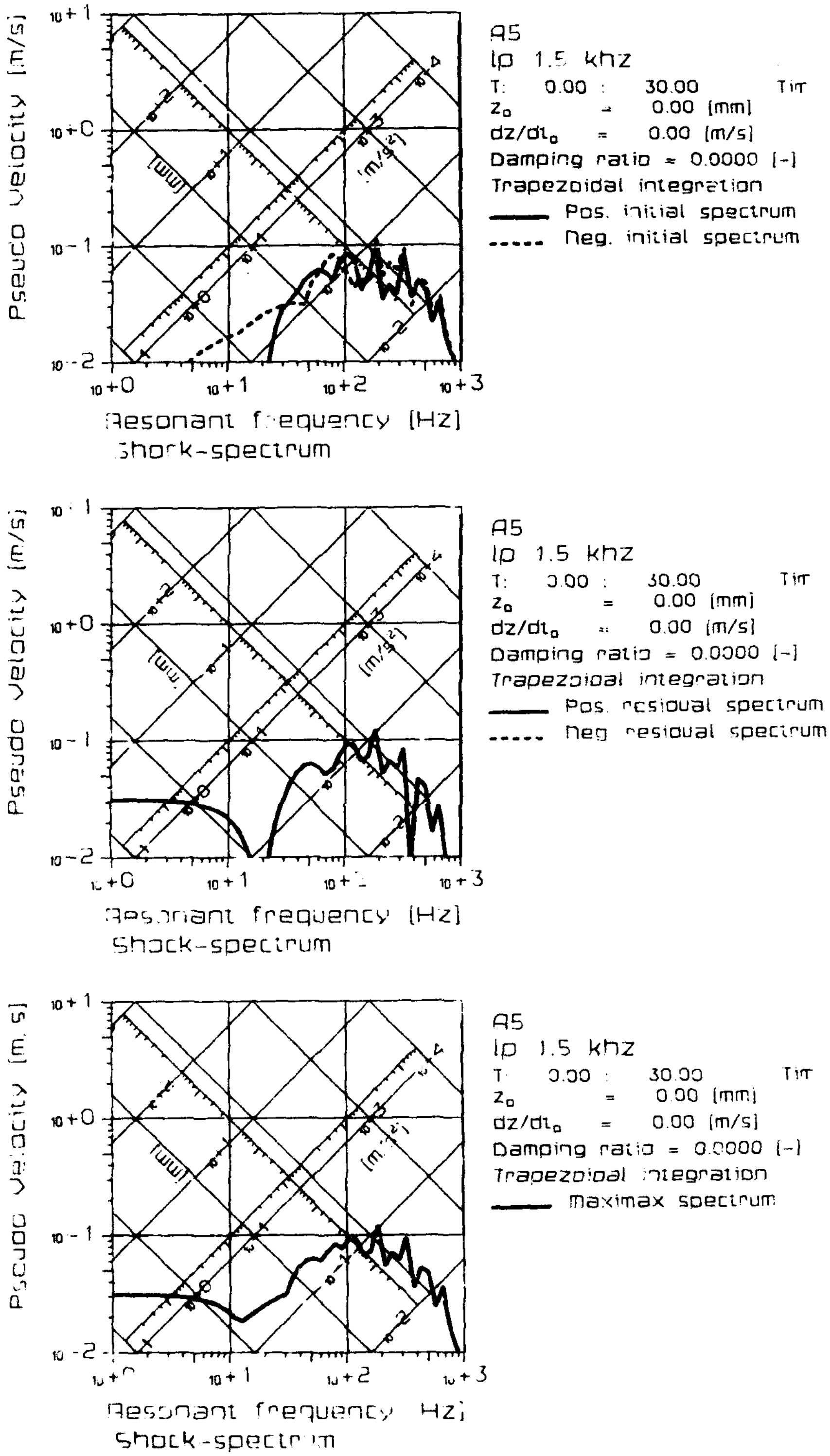


Figure 40 Shock spectra of accelerometer A5

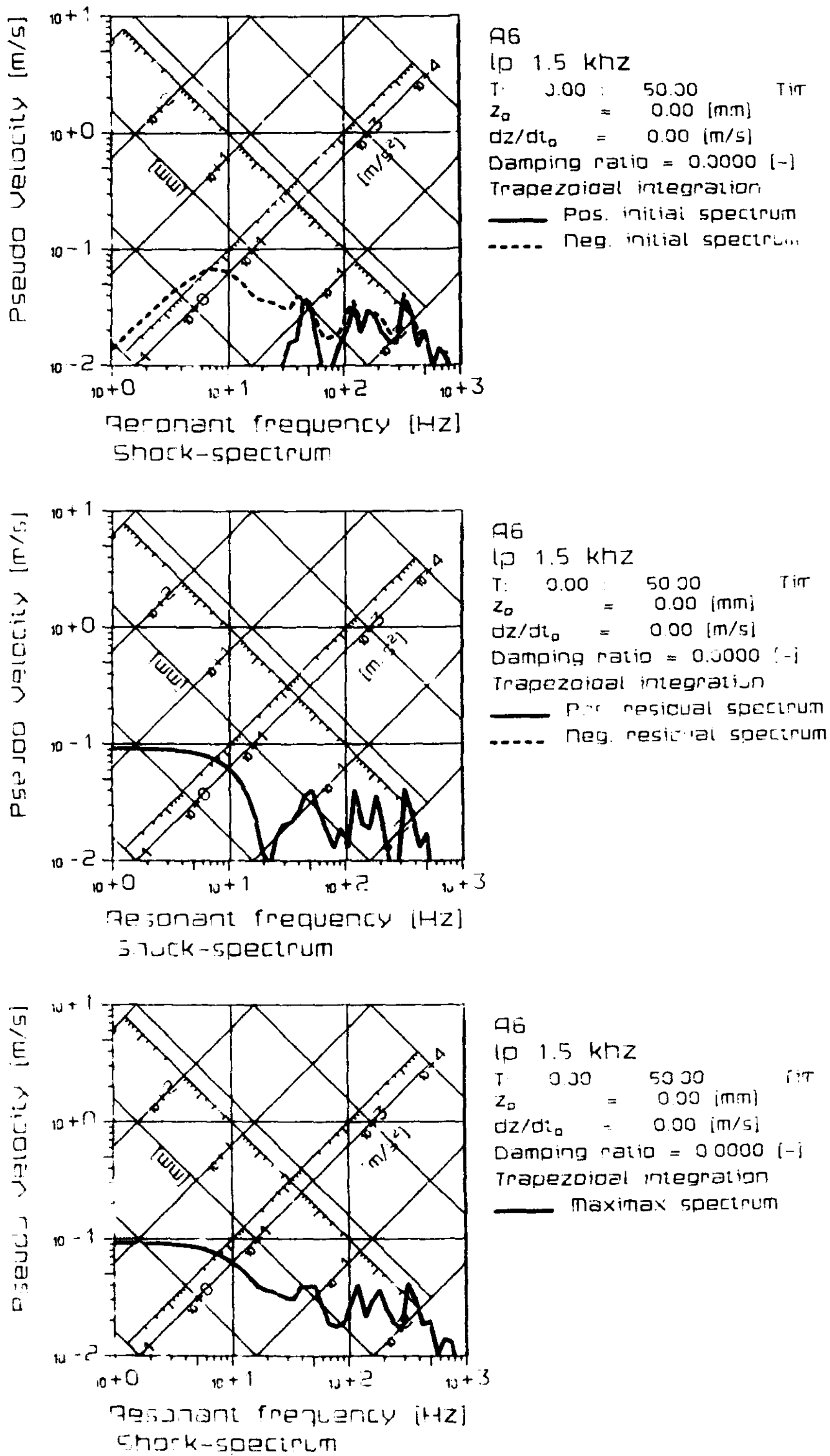


Figure 41 Shock spectra of accelerometer A6

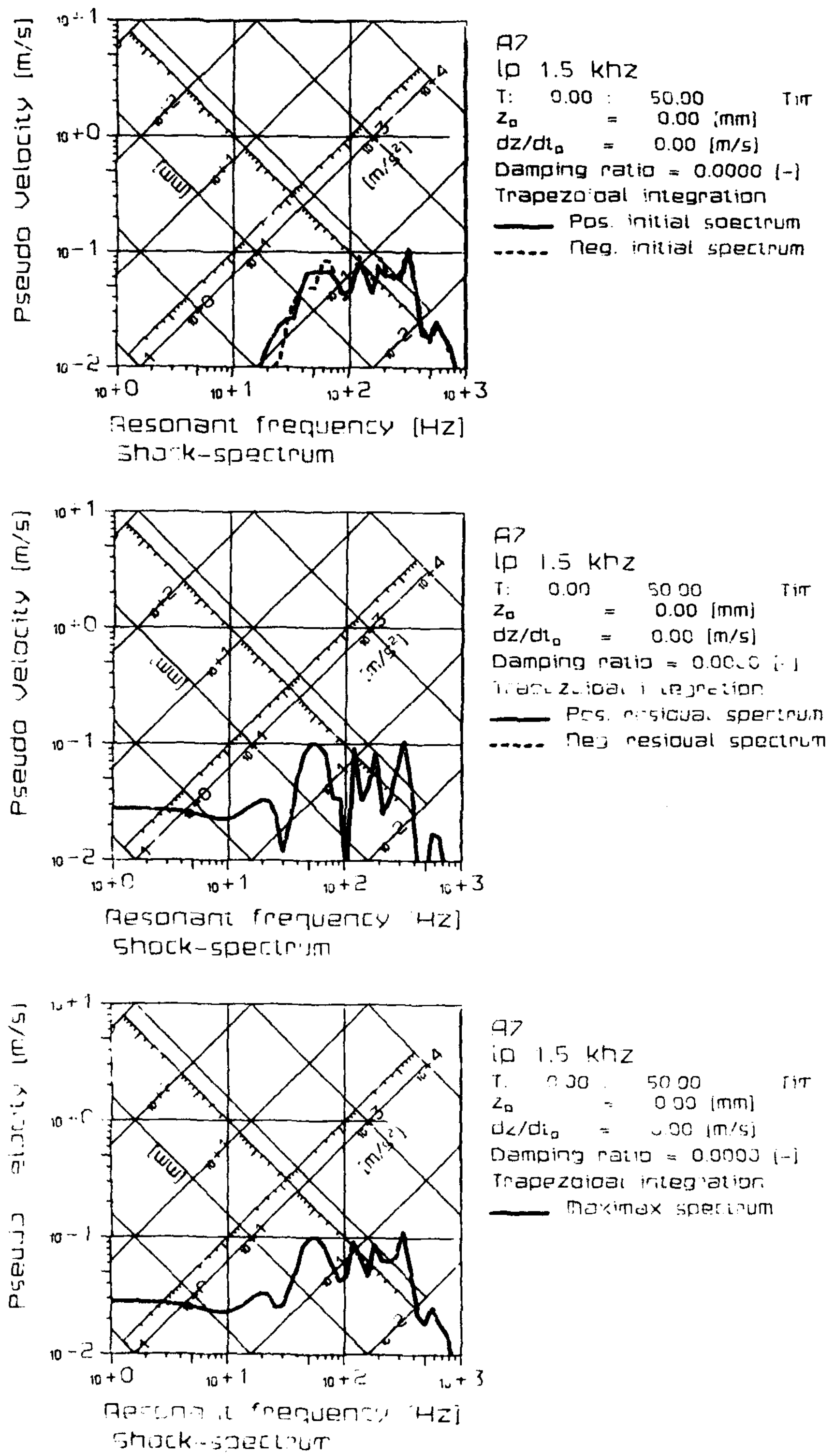


Figure 42 Shock spectra of accelerometer A7

7 TEMPERATURE MEASUREMENTS

7.1 Position of the temperature transducers

During the experiment, the temperature was measured at three locations, which are summarized in Table 10 and shown schematically in Figure 43.

Table 10 Position of the temperature transducers

Device	Height	Position
T1(1)	125 cm	beside Q1, SB, in experiment compartment
T2	118 cm	beside Q3, corporals' sleeping compartment
T3	149 cm	115 cm from CL, munition depository

(1) near venting hole

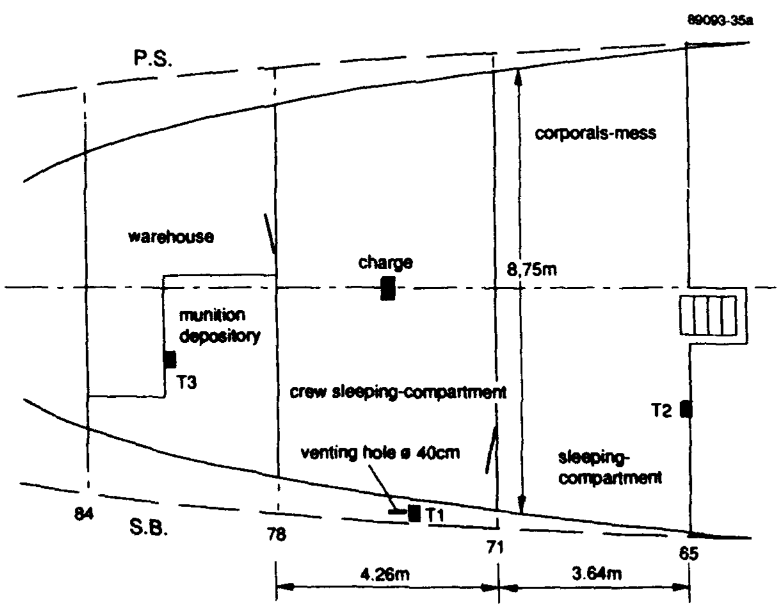


Figure 43 Schematic illustration of the positions of the temperature transducers

7.2 Discussion of the temperature measurements

In Figure 44, the recorded temperatures are shown. Note that in fact a temperature increment dT is shown and not an absolute temperature, i.e. T=0 corresponds with the ambient temperature. It appears that device T1 malfunctioned after 1 s. T2 and T3 were uniformly filtered to improve the signal-to-noise ratio. The temperature recording corresponds with the quasi-static pressure measurements.

The peak quasi-static pressure in the munition depository, divided by the peak pressure measured in the corporals' mess, leads to a factor 3, also found in the temperature measurement in these two compartments and corresponds with the volumes of these compartments. From this, it is obvious that the same amount of explosive gaseous products was leaked into the adjacent compartments.

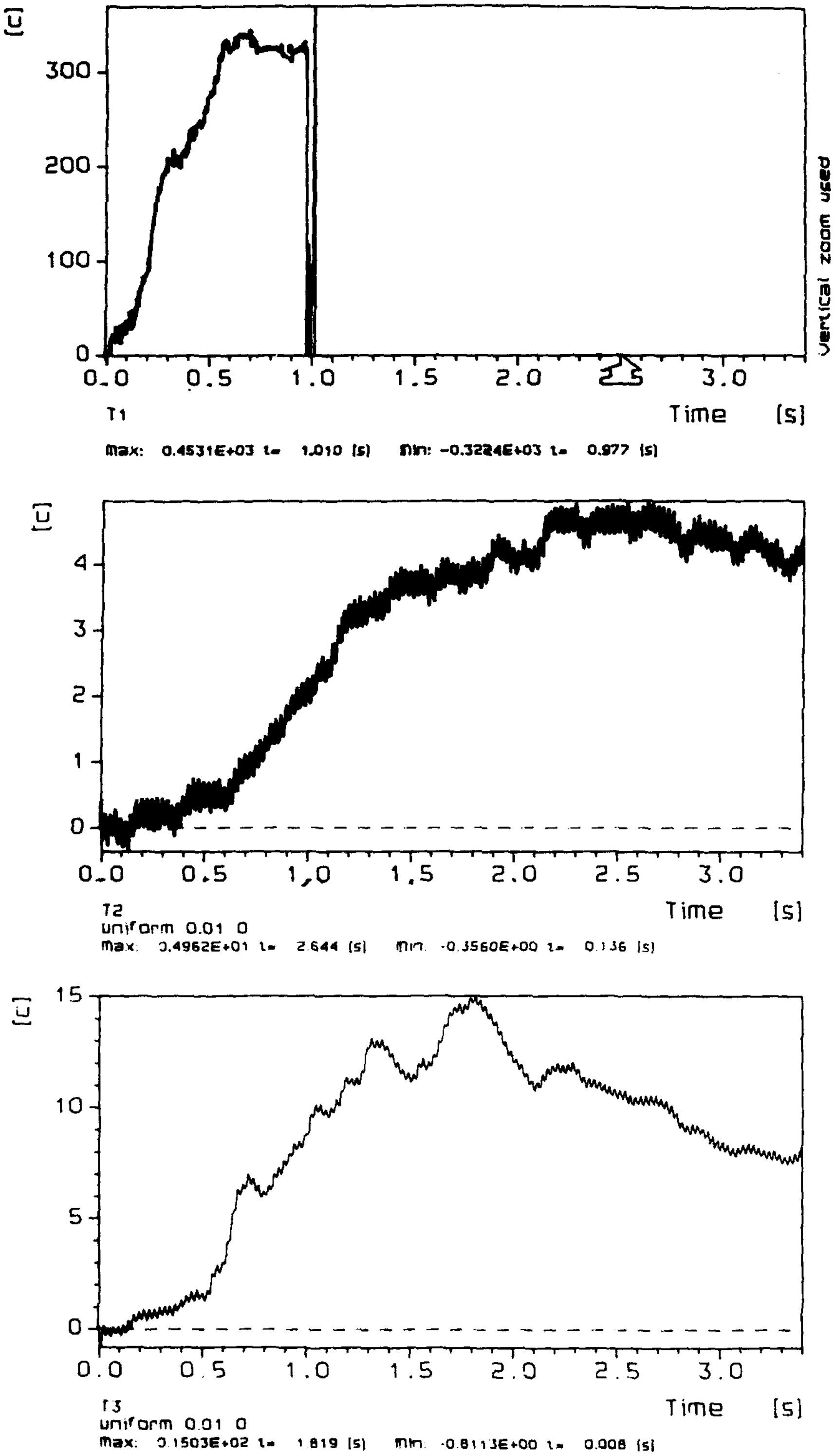


Figure 44 The recorded temperature increments

8 BREAKWIRES

8.1 Position of the breakwires

In order to be able to determine the possible moment of collapse of the watertight doors, breakwires were used. The positions of the breakwires used are summarized in Table 11 and shown schematically in Figures 45 and 46.

Table 11 Position of the breakwires

Device	Height(1)	Position
BW1	112 cm	back side of the door in BHD 71
BW2	27 cm	back side of the door in BHD 71
BW3	81 cm	back side of the door in BHD 78

(1) Height with respect to the lower side of the door

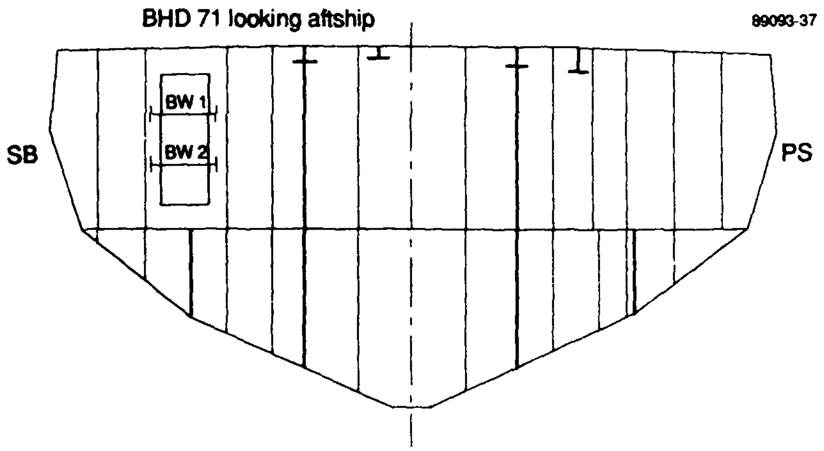


Figure 45 Schematic illustration of the positions of the breakwires in BHD 71

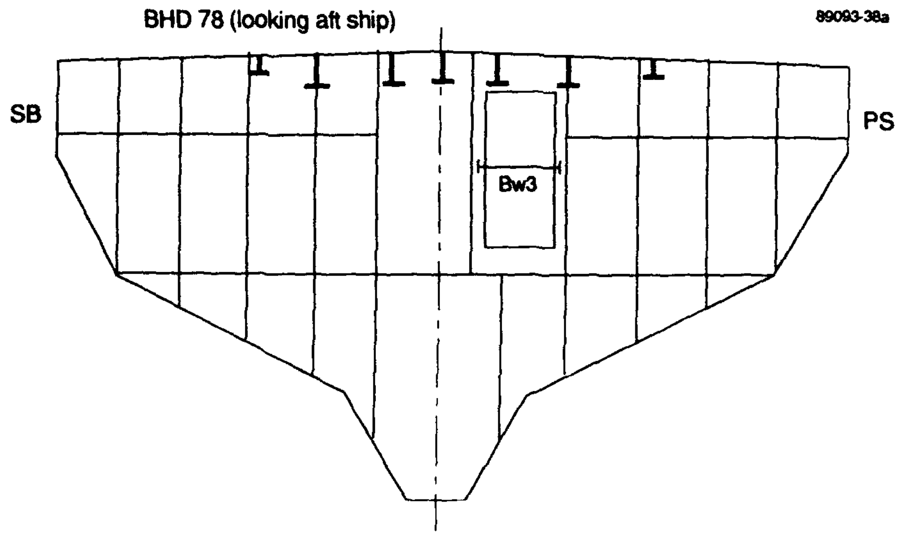


Figure 46 Schematic illustration of the position of the breakwire in BHD 78

8.2 Discussion of the breakwire measurements

The registered signals are shown in Figure 47. Note that the doors did not collapse.
Note also that strain gauge S3, mounted on the watertight door in BHD 71, starts to respond after 4.7 ms, which corresponds with the response time of BW2 and, more or less, with the response time of BW1. BW3 starts to respond after 2.5 ms, a time comparable with the arrival time of the shock front as recorded with pressure transducer B4, which was situated symmetrically to the door, with respect to the centre line of the frigate. Because the watertight doors did not collapse, it was expected that these sensors would not record any signal. The signals recorded must therefore be due to the vibration of the microswitches used in combination with the breakwires.

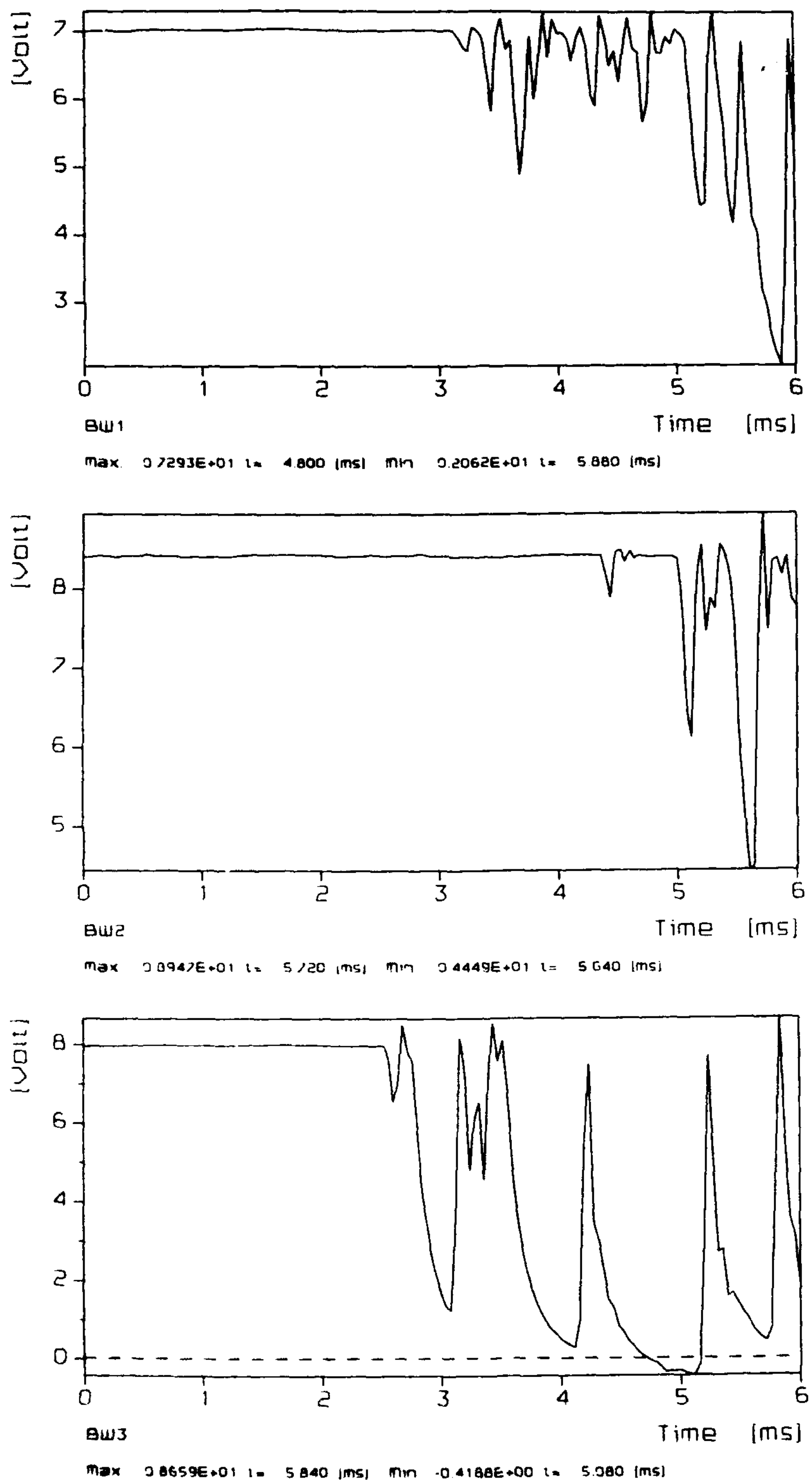


Figure 47 The breakwire signals

9 SUMMARY AND CONCLUSION

During the Wolf Phase II trial, a number of instrumented experiments in the crew forward and aft sleeping compartment were performed. During these instrumented experiments, attention was paid to the blast, quasi-static pressure, strain, acceleration, temperature and possible moment of collapse of the watertight doors. This report presents the recorded results from the 2 kg TNT experiment in the crew aft sleeping compartment. The interpretation of these recordings will be given in (van Erkel, 1992).

Because the 5.5 kg and 15 kg TNT experiment in this compartment also took place on the same day, there was little time for the technicians to adjust the settings of the registration equipment or to modify/repair the instrumentation. It is for this reason that the settings of the registration equipment were mainly based on the 15 kg TNT experiment for later that day. However, this has an effect upon the signal-to-noise ratio of the signals of this particular experiment.

The blast measurements in the experiment compartment seem to be very realistic, although some discrepancies with the theoretical predictions are noticeable. It appeared that some of the theoretical predictions (based on a centrally ignited, spherical charge) underrates the recorded peak pressures by up to a factor of 3.

The quasi-static pressure measurements in the experiment compartment correspond well with the theoretical predictions. The quasi-static pressures registered in the adjacent compartments must be due to a leakage through the doors and cracks in the walls.

Opposite-mounted strain gauges were illustrated in one figure to facilitate a better understanding of the physical processes. Two strain measurements malfunctioned and are omitted from this report. The remaining strain gauge responses show certain features. Most of the recordings show elastic deformations, although some elasto-plastic permanent deformations were recorded. Most of the opposite-mounted strain gauges show an 'in phase' behaviour, although one couple shows an 'anti-phase' behaviour. In the latter, the locally recorded elastic deformation also showed a permanent deformation, due to the global structural response.

The acceleration was measured at seven locations on the frigate. The velocity and displacement were determined by integrating these acceleration signals. These signals were adjusted by 50 Hz for distortion and drift. A third order low pass Butterworth filter was used to diminish the influence of the higher frequencies. The signals showed realistic behaviour although drift is still noticeable in some of the displacement signals. Due to the ad hoc applied signal analysis techniques, both the velocity and the displacement signals should be handled with care. The undamped shock spectra (initial, residual and maxima) of these recordings were also determined and included in this report.

The temperature measurement in the experiment compartment shows a malfunction after 1 s; the behaviour of the temperature measurements in the adjacent compartments correspond with the quasi-static pressure measurements.

Although the watertight doors in BHD 71 and BHD 78 did not collapse, the breakwires used registered signals. The moment of response could be compared with the arrival time of the shock wave and thus may be due to the vibration of the microswitches used.

From this, it can be concluded that the 2 kg TNT experiment in the crew aft sleeping compartment has resulted in a valuable set of data which can be used to validate computational prediction models and to increase the knowledge of internal explosions on frigates.

10 AUTHENTICATION

The realization of the Wolf Phase II trial as presented in this set of reports was achieved due to the effort of a number of people from the Explosion Prevention Group: the technicians, Mr. M.L. Dirkse, Mr. Ph. van Dongen, Mr. R.M. van de Kasteele and Mr. A.M. Steenweg, who carried out the experiments and processed the recordings.

We would also like to acknowledge the supporting services of the Royal Netherlands Navy.

Date:

10 apr / 1992

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Part II: Bare charge experiments in the front sleeping compartment
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(Geïnstrumenteerde beproevingen aan boord van het fregat "WOLF". Wolf II:Meetresultaten van de 2 kg TNT beproeving van het manschappen slaapcompartiment op het achterschip .)

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14. SUPPLEMENTARY NOTES

15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

Within the framework of the research into the vulnerability of ships, an experimental investigation took place in 1989 aboard the frigate "WOLF" of the "Roofdierklasse" (PCE 1604 class) (Wolf, Phase II).

In this report recordings of an instrumented experiment in the crew aft sleeping compartment are presented.

During this experiment, a non-fragmenting charge of 2kg TNT was initiated.

16. DESCRIPTORS	IDENTIFIERS
Frigates	Pressure Measurement
Vulnerability	Strain Measurement
Experimental Investigation	Accelerometers
TNT	Temperature Measurement
Explosion Effects	
Blast Measurement	

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